Project Title: Assessment of Nonpoint Source Impacts on Groundwater Quality in South Elkhorn Creek Basin, Central Kentucky (BMU 1, Round 2)

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EXECUTIVE SUMMARY

The primary goal of this project was to determine Nonpoint Source (NPS) pollution impacts to groundwater in the South Elkhorn Creek watershed in Central Kentucky, with a secondary goal to assess its influence on surface-water quality. The headwaters of South Elkhorn Creek originate in northern Jessamine and western Fayette counties within the boundaries of rural, urban and residential areas. The stream flows northwestward through Woodford, Scott and Franklin counties to its confluence with North Elkhorn Creek at the Forks of Elkhorn in southeastern Franklin County. Portions of the South Elkhorn Creek drainage have been placed on the Kentucky 303d List of Waters, which is a list of waters that do not or are not expected to meet state water quality standards for their designated use(s). Impaired reaches include sections of South Elkhorn Creek, Town Branch and Wolf Run. These reaches have been listed due to Partial- or Non-Support of designated uses, including aquatic life and primary contact recreation. Impacts to surface water include siltation, pathogens, nutrients, heavy metals, organic enrichment, and low dissolved oxygen. Non-point sources of pollution cited are agricultural and urban runoff and storm sewers.

Twenty-two springs were monitored over the course of two years for numerous water quality indicators including bulk parameters, major inorganic ions, metals, pesticides, residues, nutrients, volatile organic compounds and bacteria. Also, historic data were available for two of these springs that had been part of the Statewide Ambient Groundwater Monitoring Network since its inception in 1995. Several dye traces were conducted in the study area to delineate or better define karst groundwater basins.

Groundwater quality sample results indicate definite NPS impacts to groundwater from *E. coli*, pesticides, total suspended solids (TSS), nitrate (as N), orthophosphate (as P) and total phosphorus. Potential NPS impacts were noted for chloride. Little or no correlation has been identified between land use types (agricultural vs. urban/residential) and overall groundwater quality.

For this study, twelve tracer tests were recovered which allowed for the delineation of two additional karst groundwater basins and identification of other previously unknown hydrologic connections. These data in combination with previous tracer data were used to assess USGS Hydrologic

Unit Code (HUC) delineations for surface watersheds. Karst groundwater basin deviations from topographic watershed divides have serious implications for hydrologic modeling, TMDL development and emergency responders.

INTRODUCTION and BACKGROUND

The Kentucky Division of Water (DOW) has adopted an integrated approach to the management of water resources. This approach, known as the Kentucky Watershed Framework, is ". . . a means for coordinating and integrating the programs, tools and resources of stakeholders to better protect, maintain and restore the ecological composition, structure and function of watersheds and to support the sustainable uses of watersheds for the people of the Commonwealth" (KDOW, 2002a). Under this system, the watersheds of the state are sub-divided into five Basin Management Units (BMUs). As part of the data gathering and assessment efforts of the watershed approach, the DOW assessed nonpoint source pollution impacts to groundwater within South Elkhorn Creek watershed, a tributary to Elkhorn Creek, which is part of the Kentucky River basin (BMU 1).

Before 1995, ambient groundwater quality data throughout the state were inadequate to assess groundwater quality on a regional, basin-wide or statewide scale. In order to correct this situation, DOW initiated statewide ambient groundwater monitoring in 1995 to begin the long-term, systematic evaluation of groundwater quality throughout the state. In 1998, legislation established the Kentucky Interagency Groundwater Monitoring Network, which formalized groundwater assessment efforts. Coordination of this network is conducted by the Interagency Technical Advisory Committee on Groundwater, which includes DOW along with other state and federal government agencies.

DOW regularly collects ambient groundwater samples throughout the state. To date, the division has collected more than 5,500 samples from approximately 525 sites. The information from these samples is used for a variety of purposes, including: 1) assessment and characterization of local and regional baseline groundwater quality; 2) documentation of spatial and temporal variations in groundwater quality; 3) support of public water systems, especially through source water characterization and Wellhead Protection; 4) development of Total Maximum Daily Loads (TMDLs) for surface water in areas where groundwater directly influences this resource; 5) support of the state's pesticide management plan; 6) development of groundwater quality standards and aquifer classification; and 7) to address compliance and nonpoint source issues. DOW forwards analytical data to the Kentucky Geological Survey (KGS) Ground-Water Data Repository where it is available to the public. Data requests can be made via the KGS website (http://kgs.edu/KGS/home.htm), by phone at (859) 257-5500, or by mail at 228 Mining and Minerals Resources Building, University of Kentucky, Lexington, KY 40506.

In electronic versions of this report, Figures 1, 4, 5, 8 and 10-35 are accessible by clicking the blue reference "hyperlink". In paper reports these same figures are available in an addendum.

Project Description. This project was designed to determine NPS pollution impacts to groundwater in the South Elkhorn Creek basin. Initially, twenty-one springs within the South Elkhorn Creek basin were monitored over the course of one year. Some historical data from the Groundwater Monitoring Network were included for this study. Sites were sampled approximately six times each, over the course of one year, for metals (total & dissolved), nutrients, bulk parameters (pH, conductivity and hardness), major inorganic ions, volatile organic compounds, pesticides, herbicides and caffeine (as a potential indicator of anthropogenic impacts). Additionally, twenty of these springs were sampled once a month, from March 2004 through July 2004, for Total Coliform, Fecal Coliform and Escherichia Coli (*E. coli*) bacteria.

Additional monitoring was conducted at four springs in the basin. These springs were sampled monthly over the course of one year for the same set of parameters listed above. The goal was to obtain better data on the temporal variation of groundwater quality in the Inner Bluegrass Karst Region. Three of the springs were targeted because they drain directly to South Elkhorn Creek tributaries that have been listed as impaired. The fourth spring was chosen because it is one of the largest springs in the study area for which water quality data were lacking.

Figure 1 shows the study area of South Elkhorn Creek and its basin in Franklin, Scott, Woodford, Fayette and Jessamine counties. The headwaters originate in northern Jessamine and western Fayette counties and flow northwest to the confluence with North Elkhorn Creek in Franklin County. Agriculture represents 71% of the basin land use (56% pasture, 15% row crop). Forest makes up approximately 14% of the basin's land cover and Urban/Residential areas compose 14% (USGS, 2001). The majority of the urban and residential areas occur at the headwaters of several tributaries to South Elkhorn Creek (Town Branch, Wolf Run, Cave Creek and Brannon Run). The South Elkhorn Creek basin lies entirely within the Inner Bluegrass Physiographic Region of central Kentucky. The dominant bedrock in the region is primarily flat-lying Ordovician limestone and shale.

Previous Investigations. Watershed-specific discussions of groundwater quality for South Elkhorn Creek were not found in the literature. However, numerous authors have investigated groundwater in the Inner Bluegrass Physiographic Region of Kentucky. Some of these documents include groundwater quality of select springs and wells within the South Elkhorn Creek basin. Several investigators have conducted tracer tests to delineate karst basins within the South Elkhorn Creek watershed and results of these traces have been compiled by Currens and others (2002). Previous tracer tests will be discussed in more detail with the results of those conducted for this study.

Webb and others (2004) found definite NPS pollution impacts to groundwater in the Bluegrass Region (Inner and Outer combined) of BMU 1 (Kentucky River basin) from select pesticides, BTEX compounds (benzene, toluene, ethylbenzene and xylenes) and methyl tertiary butyl ether (MtBE). This conclusion was based on the detection of these compounds in groundwater samples, coupled with the fact that none of them occur naturally. Possible NPS pollution impacts were noted for lead, some nutrients and some residues (total suspended solids (TSS) and total dissolved solids (TDS)). These parameters were characterized as possible NPS pollution because their occurrence frequency and concentrations were suspect, although they do occur naturally in the environment.

Carey and others (1994) also investigated groundwater quality in the Kentucky River basin. They reported that groundwater in the counties drained by South Elkhorn Creek tends to have levels of nutrients, anions and pesticides that were at or above average when compared with concentrations in groundwater across the state. They also noted that springs are the most significant source of groundwater in the Kentucky River basin.

Thrailkill and others (1982) note that due to the dendritic pattern of karst drainage systems, NPS contaminants can be introduced across a large area and coalesce to be discharged at a single spring. Thus, NPS pollution can be concentrated at one spring that may provide water for municipal, domestic or livestock use. Conversely, well-developed karst drainage may also have a radial discharge pattern from topographic highs, allowing contaminants from a single source to be dispersed over a large area (Ray and O'Dell, 1993).

The United States Geological Survey (USGS) prepared Hydrologic Atlases (HA) for the entire state. The basin for South Elkhorn Creek is split between HA-24 and HA-25. These atlases primarily address groundwater derived from wells although they do mention a few large springs developed in the Lexington Limestone. Data for springs are limited to discharge measurements and estimates, and no spring water-quality data are included. Carey and Stickney (2001) produced county groundwater resource maps for the entire state. Ray and others (1994) delineated groundwater sensitivity regions for Kentucky, based on geology and flow regime. Sensitivity ratings were based on groundwater recharge porosity, flow, velocity and dispersion potential. The Inner Bluegrass Region of Kentucky, including the South Elkhorn Creek basin, was rated as highly sensitive to groundwater contamination.

For the Inner Bluegrass Region, Hamilton (1950) found that little or no significant potable water was encountered by water wells completed at depths greater than 100 feet below ground surface. He stated that the yield of shallow wells is controlled by the size of any conduits encountered while drilling and that approximately only 20% of wells have adequate yield and quality of water.

PHYSIOGRAPHIC and HYDROGEOLOGIC SETTING

South Elkhorn Creek Basin. The South Elkhorn Creek basin encompasses 186 square miles in portions of Franklin, Scott, Woodford, Fayette and Jessamine counties. The headwaters of South Elkhorn Creek rise in northern Jessamine and western Fayette counties then flow roughly northwest to its confluence with North Elkhorn Creek, forming the main stem of Elkhorn Creek. Approximately 300 miles of surface drainage flow through the basin. Due to well-developed karst drainage, numerous dry valleys occur in the basin. Major tributaries to South Elkhorn Creek include Town Branch, Brannon Run, Wolf Run and Cave Creek, all of which drain urban and residential areas. Elevations in South Elkhorn Creek basin range from 650 feet at the mouth to 1060 feet along the southeastern divide. The entire basin is located within the Inner Bluegrass Physiographic Region. Total population in the basin is approximately 250,000, concentrated mainly in Lexington, around the headwaters of Town Branch, Wolf Run and Cave Creek.

Physiographic Region. South Elkhorn Creek is located entirely within the Inner Bluegrass Physiographic Region of central Kentucky. The Inner Bluegrass Region is underlain by Ordovician-age limestone and shale. In general, relief is low and the area is characterized by gently rolling hills with sinkholes and moderately thick soils on uplands. Although numerous karst features, such as sinkholes, dry valleys, caves and sinking streams, occur in this region, most terrain is moderately dissected by surface streams.

Karst Hydrology. Karst can be essentially defined as "having the potential for turbulent conduit flow within soluble rocks" (Ray and Idstein, 2004). Although sinking streams, sinkholes, caves and large springs occur in well-developed karst, these features are not required for a karst terrane (Ray, 2008). Karst terrane denotes a type of topography and its hydrology where soluble rock, such as limestone or dolostone, is present at or near the land surface. Karst terrane is characterized by underground channels, or conduits, formed through the dissolution of these rocks, primarily by turbulent groundwater with relatively *anisotropic* flow. Karst terrane may also contain naturally occurring closed topographic depressions, or sinkholes, with internal drainage, springs, caves, and losing or sinking streams (Figure 2). The traditional idea of a water table may not apply, in many cases, because of relatively nonporous limestone and hydrologic confinement. Karst drainage networks in Kentucky range in magnitude from shallow perched systems that drain a few acres to large groundwater basins up to 20 miles in length. The grandiose Mammoth Cave of south central Kentucky is the longest known cave system in the world with several hundred miles of interconnected conduits and caverns developed in a multi-level system.

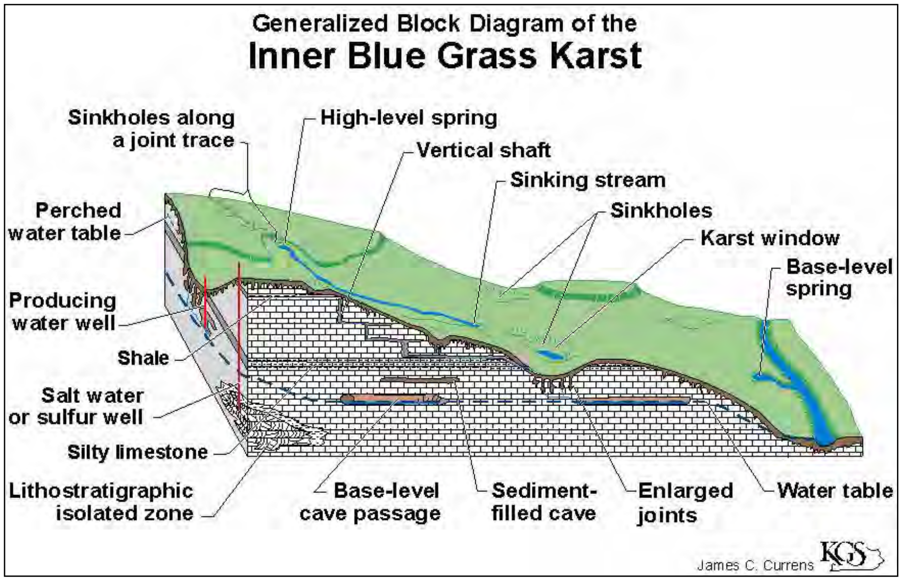

Figure 2. Generalized Karst Diagram by Jim Currens (KGS)

In karst terrane, recharge, in the form of precipitation or snowmelt, moves into the subsurface primarily by dispersed percolation through the soil, but also by concentrated flow via sinkholes and stream swallets (sinking/losing streams). Water may be seasonally stored in the soil and *epikarst,* the shallow zone of regolith and fractured, weathered bedrock, perched above the regional conduit network. In the epikarst, the moisture may be stored and slowly released into the lower section of the drainage network by seepage and/or percolation. The water could also be locally discharged from shallow, perched springs (depending on the specific geology of the site). From the epikarst system, moisture may flow through vertical fractures or along nearly horizontal bedding planes until it reaches the major conduit (or cave) network.

Eventually, the conduit or cave network will discharge to the ground surface at a spring. Depending on the geology of the area, these conduit networks may be measured in yards or miles. Spring morphology also varies from site to site depending on the geologic setting. *Gravity springs* discharge water from a point above local base level sometimes creating spectacular waterfalls and cascades. Many springs discharge from the base of a bluff, flowing through mounds of talus ranging in size from gravel to boulders. *Bluehole springs* discharge from near-vertical fractures or conduits where the water is under sufficient hydrostatic pressure to force it upward. Blueholes are generally observed as pools, sometimes with turbulent 'boils' forming on the surface, especially during high-flow conditions. A minor type of spring is termed a 'seep', where water infiltrates through the rock or soil and is discharged as a trickle or film.

Overflow springs are discharge points that are only active during high-water conditions. They may be storm-related or seasonal in duration. *Estavelles* are unique overflow springs that also function as stream sinks during low flow. *Karst windows* are features in which a portion of a conduit or cave system is exposed to the surface due to roof collapse. Karst windows appear as springs discharging in sinkholes which then re-enter the subsurface. *Cutoff* springs occur when a surface stream is diverted into the subsurface and re-emerges a short distance away. Cutoff springs usually have only minor groundwater inputs and water quality deviates little from that of the surface stream (Ray and Blair, 2005). Some springs are large enough to be the headwaters of a surface stream and maintain base flow during times of little or no precipitation. Smaller springs also function as tributaries to surface streams.

Hydrogeology of South Elkhorn Creek basin. The principle karst aquifer in the South Elkhorn Creek basin is the Lexington Limestone Formation of the middle and upper Ordovician stratigraphic sequence.

In particular, all of the study area springs discharge from either the Tanglewood Limestone Member or the Grier Limestone Member. Complex inter-tonguing of individual members of the Lexington Limestone Formation exists throughout the watershed. The Tanglewood Limestone is characterized as medium- to medium-dark-gray, fine- to coarse-grained, bioclastic, generally phosphatic and thinly bedded, with unit thickness ranging from 90 to 130 feet (Pomeroy, 1970). Pomeroy (1970) also describes the Tanglewood as containing minor shale units and some cross-bedded limestone within the unit as a whole. The Brannon Member, located near the bottom of the Tanglewood Limestone, where it inter-tongues with the Grier Limestone, is described by Pomeroy as a thin limestone and shale sequence which is light- to medium gray, micrograined to very fine grained and thinly bedded with sparse fossils. The Grier Limestone Member as described by Pomeroy is light- to dark-gray, micro- to coarse-grained (mostly medium-grained), thinly bedded, bioclastic and slightly phosphatic, and typically on the order of 85 feet thick. Surface and subsurface karst features are common in both the Tanglewood and Grier Limestone Members. Although local variation does exist, these units generally have a gentle dip to the northwest.

Faulting within the South Elkhorn Creek study area is minor and no regional fault systems intersect the watershed. The most notable faulting is associated with the possible impact structure located northeast of Versailles which is believed to have occurred during the late Ordovician Period (~440 Ma) (Black, 1964). This site is described as a cryptoexplosive structure because no direct evidence of meteorite impact has been found. The associated faults are seen as nearly circular in plan view and are pronounced on the surface as a large ring of sinkholes. This seems to be the only area in the basin where regional groundwater flow is influenced by faulting. Figure 3 shows the generalized stratigraphic sequence of rock units in the South Elkhorn Creek basin and the relative stratigraphic position of study area springs. All study area springs occur in the Lexington Limestone, specifically just above and below the contact of the Grier Limestone Member and the overlying Tanglewood Limestone Member. Figure 4 is a geologic map of the watershed.

Adapted from Pomery, 1970, MacQuown and Dobrovolny, 1968 and Miller, 1967

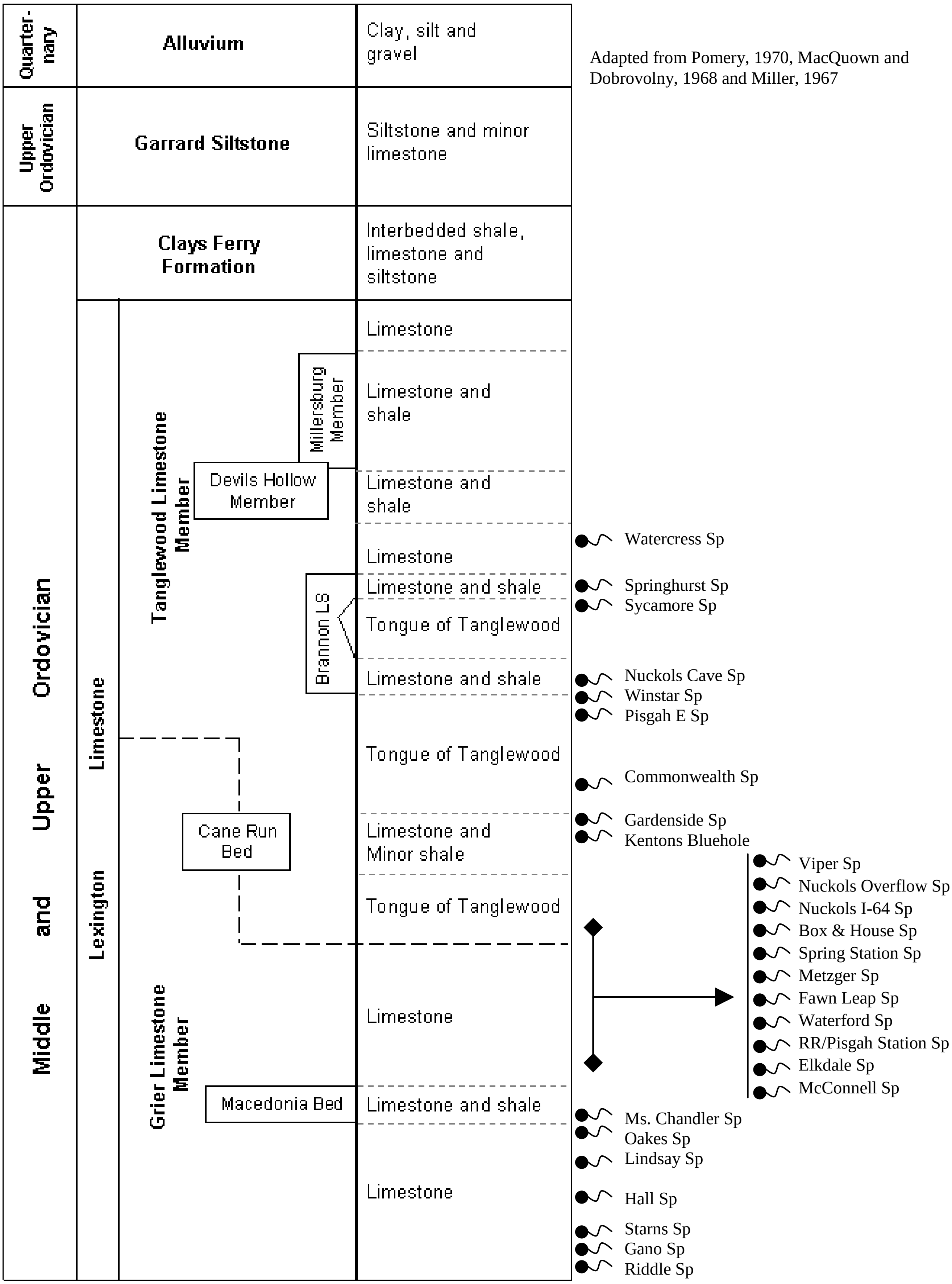

Figure 3. Generalized Stratigraphic Column

Unit Base Flow (UBF), which is the ratio of spring base flow to spring basin area, is a powerful tool employed for karst groundwater basin delineation (Quinlan and Ray, 1995 and Paylor and Currens, 2001). Applying the appropriate UBF assessment to base-flow spring discharge measurements allows for reasonable estimation of spring basin size. When coupled with tracer test data, the UBF assessment aids in determining the geographic extent of a spring's recharge area. For the purposes of this study, UBF will be expressed as cubic feet per second per square mile ($ft^3/s/mi^2$); conversion factors are available in Appendix C. Paylor and Currens (2001) determined UBF for the Inner Bluegrass Region to be 0.03 $ft^3/s/mi^2$. However, Paylor and Currens noted anomalously high UBF for Inner Bluegrass springs draining urban areas (up to 0.38 $ft^3/s/mi^2$). They identified potential causes for the observed deviations as leaking water-supply and wastewater lines. Excessive lawn and garden irrigation may also play a role in the elevated UBF found in these urban springs (Ray, 2007, oral comm.).

Groundwater yield from study area springs is highly variable. Some spring discharge rates display quick response to recharge events while others show little flow variation. Base-flow measurements and estimates for study area springs ranged from 0.01 cubic feet per second (cfs) to 0.6 cfs (Table 1). Figure 5 shows the study area with springs monitored for water quality and four sub-watershed designations used for statistical analyses based on the USGS 12-digit Hydrologic Unit Code (HUC) delineations.

AKGWA	Spring Name	Base-flow Discharge (ft^3/s)	County	Water Quality Data	Use	Predominant Land Use	Sub-basin
3350	Nuckols Overflow	Dry	Woodford	No	Not Used	Pasture	
3336	Winstar	Trickle	Woodford	Yes	Not Used	Pasture	HW South
	RR/Pisgah Station	Trickle	Woodford	No	Not Used (***H***)	Pasture	
3345	Watercress	0.01 ***M***	Woodford	Yes	Not Used	Pasture/Row Crop	Lower
3294	Viper	0.01 ***M***	Scott	Yes	Not Used (***H***-domestic)	Pasture	Lower
1539	Starns	0.01	Scott	Yes	Livestock	Pasture	Middle
0308	Oakes	0.02	Jessamine	Yes	Not Used	Light Residential	HW South
3338	Sycamore	0.05	Woodford	Yes	Domestic/Livestock	Pasture	HW South
2593	Nuckols Cave	0.05	Woodford	Yes	Livestock	Pasture	Lower
3249	Pisgah E	0.05	Woodford	Yes	Livestock	Pasture/Row Crop	HW South
0157	Gardenside	0.05	Fayette	Yes	Not Used (***H***)	Urban/Residential	HW North
2592	Nuckols I-64	0.05	Woodford	No	Livestock	Pasture	
3325	Box & House	0.05	Woodford	Yes	Livestock (***H***-domestic)	Pasture	Lower
3054	Metzger	0.05	Woodford	Yes	Livestock	Pasture	Middle
3332	Ms. Chandler	0.05	Fayette	Yes	Domestic	Pasture	HW South
2417	Hall	0.05	Fayette	Yes	Not Used (***H***)	Pasture	HW South
1542	Gano	0.05	Scott	Yes	Livestock	Pasture	Middle
3689	B. Riddle	0.1	Scott	Yes	Not Used (***H***-distillery)	Pasture/Residential	Lower
0159	Springhurst	0.1	Fayette	Yes	Pond	Urban/Residential	HW North
0253	Commonwealth	0.1	Fayette	Yes	Ponds	Commercial/Industrial	HW North
	Elkdale	0.1	Woodford	No	Livestock	Pasture	
3383	Waterford	0.12 ***M***	Woodford	Yes	Domestic/Livestock	Pasture	Middle
0081	Fawn Leap	0.15 ***M***	Woodford	Yes	Not Used (***H***-domestic)	Pasture	Middle
0124	Kentons Bluehole	0.2	Fayette	Yes	Not Used (***H***)	Urban/Residential	HW North
0111	Lindsay	0.25	Fayette	Yes	Not Used	Residential	HW North
1200	Spring Station	0.5 ***M*** **	Woodford	Yes	Not Used (***H***)	Pasture	Lower
1161	McConnell	0.6 ***M*** *	Fayette	Yes	Not Used	Urban/Residential	HW North

Table 1. List of Study Area Springs. Base-flow Discharge: *M* = Measured Spring Discharge, all others estimated; * Measurement by Gary O'Dell and Jo Blanset (DOW), ** Measurement by Joe Ray (DOW). Use: (*H*) = Historical Use-defined if known; Sub-basin column denotes one of four internal watersheds – specified only for sites with Water Quality Data (HW = Headwaters)

Land Cover and Land Use. Land-use types and amounts for South Elkhorn Creek basin were derived using GIS land cover analysis provided by the USGS (2001) and by observations in the field. Land-use change due to recent residential development that replaced former agricultural land has been estimated. The predominant land use in South Elkhorn Creek basin is agriculture, which represents 71% of the surface area (Table 2). Specifically, pasture land occupies approximately 56% of the land surface; row crops account for the remaining 15%. Forested areas and wetlands occupy approximately 14% of the basin, mainly in the form of deciduous forest and mixed deciduous-evergreen forest. Forested areas occur as isolated pockets and none of the springs monitored for this study drained predominantly forested areas. Urban and residential areas represent about 14% of the basin's land cover – this figure includes commercial and industrial areas. Potential contaminants related to major land use categories are outlined in Table 2.

Landcover	Percent of basin area	Potential Contaminants
Agriculture, including row crop production and livestock grazing	71	Pesticides, nutrients (esp. nitrate-N), salts/chloride, volatile organics, bacteria
Urban and residential	14	Pesticides, volatile organics (BTEX and MTBE), chlorides
Forest and wetlands	14	Metals, pesticides, nutrients, sediment, pH

Table 2. Study Area Landcover and Potential Nonpoint Source Contaminants

Leaking sewer lines represent a potentially significant source of groundwater contamination in urban and residential areas. This problem was exemplified in the South Elkhorn Creek watershed by tracer tests at one spring discharging to Town Branch in Lexington. Mystery Spring, which was not monitored for this study, was impacted by a leaking sewer trunk near Chair Avenue in downtown Lexington during the summer and fall of 2007. Sewage discharging from this spring created a turbulent boil and severely degraded water quality in Town Branch. Systematic tracer tests conducted in the sewers, with cooperation from the Lexington-Fayette Urban County Government, confirmed a hydrologic connection between one sewer trunk line and Mystery Spring. These data were then used to isolate the leaking 2000-foot section of sewer trunk so that appropriate repairs could be made. Although contamination of this magnitude was not found in any of the springs monitored for this study, it provides evidence of an aging infrastructure with the potential to contaminate groundwater (Lyne and Blair, 2008).

Sinkholes occupy approximately 3 square miles (1.7%) of the basin’s surface area, based on closed depressions digitized from the 1:24,000 USGS 7.5’ quadrangles by the Kentucky Speleological Survey (2004). Interestingly, of the 3 square miles of mapped sinkholes, the majority - approximately 77% - fall within land used for agricultural purposes. Boyer and Alloush (2001) studied the distribution of nitrogen in soil on a karst terrane by comparing sinkholes where livestock had access to graze versus those where livestock were denied access. They found increased ammonium-N and nitrate-N in the sinkhole where livestock were allowed to graze. This may be attributed to increased visitation by livestock and movement of soil and fecal matter by water and gravity. Higher concentrations of ammonium-N were found in shallow soil layers, while nitrate-N concentrations increased with soil depth. Boyer and Alloush state that this may be due to nitrogen cycling and the more soluble nitrate-N being leached from the shallow soil layers. The exception to this was near the center drain of the sinkhole where cover-collapse caused mixing of the soil layers. These findings have important ramifications for pasture land on karst terranes utilized for livestock, such as those in the South Elkhorn Creek basin where nutrients and pathogens have been identified as NPS contaminants of concern.

Groundwater Use. During the course of this study very few domestic groundwater sources were encountered. The most common groundwater usage in the basin is for livestock water, but groundwater use for domestic purposes was historically prevalent throughout the basin. Numerous springs were developed as domestic and public groundwater sources when the area was originally settled in the late 18^{th} century. Many historic spring houses, spring boxes and distribution systems can still be found. However, most of these have been abandoned for municipal water supplies and are currently used for agricultural purposes or maintained simply for their historical value. Please refer back to Table 1 for usage details for each of the study area springs.

METHODOLOGY

NOTE: *The discussion below has been compiled or quoted verbatim from existing* [former] *Groundwater Branch NPS reports (O'dell and others, 2006; Ray and others, 2006) that have used essentially the same Materials and Methods.*

Introduction. Parameters that are most indicative of NPS pollution, as well as those necessary to characterize natural groundwater chemistry, are shown in Table 3. Included are values for each parameter that were used for comparison with data collected from study area sites. Basic water quality can be determined from common, naturally-occurring inorganic ions, metals, residues, specific conductance (conductivity) and pH. Parameters that do not occur naturally, such as pesticides and most volatile

Parameter	*Standard*	*Source/Discussion **
Bulk parameters		
Conductivity	800 μmho	No MCL, SDWR, or HAL; this roughly corresponds to 500 mg/L TDS, which is the SDWR
pH	6.5 to 8.5 pH units	SDWR
Inorganics		
Chloride	250 mg/L	SDWR
Fluoride	4 mg/L	MCL
Sulfate	250 mg/L	SDWR
Metals		
Arsenic	0.010 mg/L	MCL
Barium	2 mg/L	MCL
Iron	0.3 mg/L	SDWR
Manganese	0.05 mg/L	SDWR
Mercury	0.002 mg/L (0.00077 mg/L)	MCL (WAH)
Nutrients		
Ammonia-N	0.110 mg/L	DEP
Nitrate-N	10 mg/L	MCL
Nitrite-N	1 mg/L	MCL
Orthophosphate-P	0.04 mg/L (0.1805 mg/L)	No MCL, SDWR, or HAL; Texas surface water standard (KDOW-GWB)
Total phosphorous	0.3 mg/L	No MCL, SDWR, or HAL; level used by KDOW-WQB TMDL
Pesticides		
Alachlor	0.002 mg/L	MCL
Atrazine	0.003 mg/L (0.00067 mg/L)	MCL (DEP)
Cyanazine	0.001 mg/L	HAL
Metolachlor	0.1 mg/L	HAL
Simazine	0.004 mg/L	MCL
Residues		
Total Dissolved Solids	500 mg/L	SDWR
Total Suspended Solids	35 mg/L	No MCL, SDWR, or HAL; KPDES permit requirement for sewage treatment plants
Volatile Organic Compounds		
Benzene	0.005 mg/L	MCL
Ethylbenzene	0.7 mg/L	MCL
Toluene	1 mg/L	MCL
Xylenes	10 mg/L	MCL
MtBE	0.012 mg/L	RSL
Pathogens		
Escherichia coli (*E. coli*)**	< 1 CFU/100 mL	MCL

Table 3. Parameters and Standards for Comparison

* Abbreviations:

MCL = Maximum Contaminant Level
SDWR = Secondary Drinking Water Regulation
HAL = Health Advisory Level
KPDES = Kentucky Pollutant Discharge Elimination System
DEP = Kentucky Department for Environment Protection risk-based number
KDOW-GWB = median value for Bluegrass Region from previous groundwater research
TMDL = Total Maximum Daily Load program
RSL = US EPA Regional Screening Level
WAH = Warmwater Aquatic Habitat Surface Water Standard in 401 KAR 10:031

** For complete explanation of *E. coli* drinking water standard refer to USEPA National Primary Drinking Water Standards.

organic compounds (VOCs), are the best indicators of nonpoint source pollution. Reference values used for comparison originate from a variety of sources. No consensus currently exists regarding the appropriateness of comparing ambient groundwater with these standards. Therefore, the derivation of these standards and their applicability to ambient groundwater are discussed below.

Many of the reference values used were established by the United States Environmental Protection Agency (U.S. EPA, 2006a) for treated, public drinking water supplies. The U.S. EPA defines three types of drinking water standards: Maximum Contaminant Levels, Secondary Drinking Water Regulations and Health Advisories:

Maximum Contaminant Level (MCL) is defined as “the highest level of a contaminant that is allowed in drinking water” (U.S. EPA, 2006a). MCLs are legally enforceable limits applied to treated, public drinking water based on various risk levels, ability to treat and other cost considerations. MCL standards are health-based and are derived from calculations based on adult life-time exposure, with drinking water as the only pathway of concern. These standards are also based upon other considerations, including the efficacy and cost of treatment.

Secondary Drinking Water Regulations (SDWR) are defined by the U.S. EPA (2006a) as “non-enforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor or color) of drinking water.” This may also be referred to as the Secondary Maximum Contaminant Level (SMCL).

Health Advisory is defined as “an estimate of the acceptable drinking water levels for a chemical substance based on health effects information; a Health Advisory is not a legally enforceable Federal standard, but serves as technical guidance to assist Federal, state and local officials.” This is commonly referred to as the Health Advisory Level (HAL) and this usage has been adopted for this report.

Regional Screening Level (RSL) is a risk-based concentration determined by using standardized equations, which combine potential exposure and toxicity data.

Many parameters discussed in this report do not have standards set by the U.S. EPA. These parameters were compared with a variety of existing standards. These include the proposed, but not adopted, Kentucky Department for Environmental Protection (DEP) standard for ammonia; the Kentucky Pollutant Discharge Elimination System (KPDES) standard for total suspended solids (TSS) discharged to surface waters; and the KDOW surface water standard for total phosphorus from the TMDL program.

Established water quality standards provide valid reference values for groundwater quality data. However, another important tool is data comparison with water quality from sites known to have minimal anthropogenic impacts. Although some parameters are derived strictly from anthropogenic sources, others can occur both naturally and through human synthesis. Therefore, reviewing land use in conjunction with current and historical geochemical data may help differentiate between anthropogenic and natural sources of a given parameter.

Statistical and Graphical Methods. Project data were evaluated using summary statistics, summary tables, box and whisker plots (boxplots) and graduated-size maps. Summary statistics for this report consist of minimum, maximum, median and mode values. Summary tables indicate number of samples, number of detections and number of detections above the particular standard of comparison for that parameter, such as MCL. Graduated size maps display analytical results as symbols that increase in size corresponding to value. These maps show the median value for each site.

The primary use of a boxplot is to visually separate data using quartiles that divide the dataset into fourths. Once constructed, the boxplot (Figure 6) will graphically depict the central tendency, or where the data cluster (a "typical value"), and the dispersion, or scatter, of the data values in the set. The dataset, after being put into rank order, is divided into fourths. The values at these divisions are depicted on the boxplot: the minimum, or Q_0; the maximum, Q_4; the median, $Q_{2,}$ (the midpoint that divides the dataset into halves); the first quartile, Q_1, (the midpoint of the lower half of the dataset); and the third quartile, Q_3, (the midpoint of the upper half of the dataset). The difference between Q_3 and Q_1 is called the Inner-Quartile Range (IQR). The IQR comprises 50% of the dataset and is represented by the box of the boxplot. The horizontal lines extending below Q_1 and above Q_3 are whiskers with fences as endpoints. The lower fence is 1.5 times the length of the IQR and is located below Q_1; the upper fence extends to 1.5 times the IQR and is located above Q_3. Any value outside this range is deemed an outlier if it is between 1.5 IQR and 3.0 IQR beyond the edge of the box, or an extreme outlier if it is greater than 3.0 IQR beyond the edge of box (Blanset, 2005). Boxplots in this report are displayed in groups to enable comparison between members of groups such as land use, spring use and watershed designation in addition to a comparison of individual sites against the combined grouping of all 22 sites in the study.

Analyte samples for which there was no detection, based on analyte-specific testing methods and test-specific detection limits, are referred to as "censored observations." A conservative approach was taken regarding these censored observations by plotting these data at their detection limit. The censored data have values between zero and the detection limit and since the detection limit is typically low, the clustering of censored observations at this detection limit does not provide an unrealistic interpretation of the overall dataset.

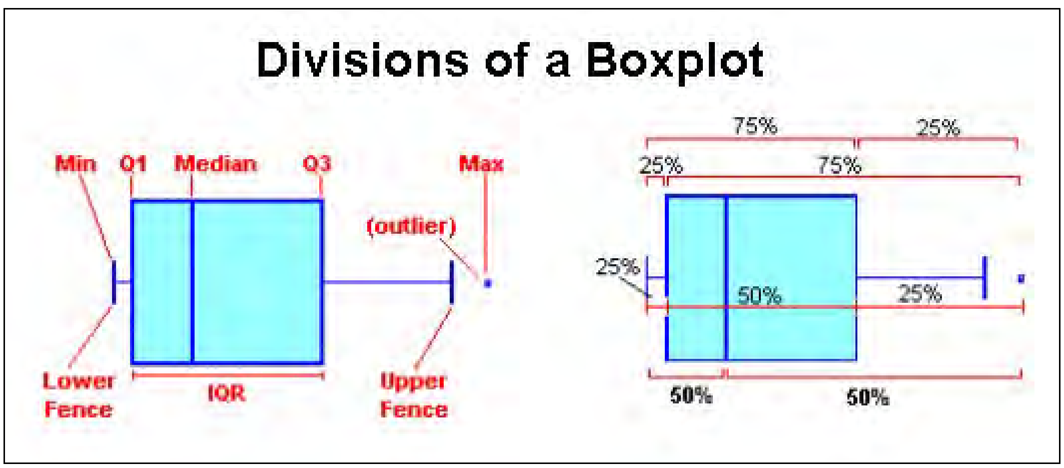

Figure 6. Boxplot Diagram

Maps created to display sample results utilize graduated color points, based on median parameter concentrations at each site, overlain on a simplified land use map with county boundaries, major surface streams and the watershed boundaries (10- and 12-digit HUCs). Individual legends indicating the range of median values for point colors are included on each map. Any parameter with a median concentration value exceeding its drinking water standard (MCL or SDWR) is also highlighted.

Maps used to show results of tracer tests conform to the standards used in the Kentucky Karst Atlas map series published by KGS with DOW. The legend for the dye-trace map can be found in Figure 7. The exception to this legend is that inferred groundwater flow routes derived from traces conducted for this study are displayed in orange so that they can be distinguished from previous investigations. Tracer data are displayed in color overlain on black and white 7.5 minute or 30 x 60 minute topographic quadrangles. All maps were created with ArcGIS 9.2 software using data obtained from the Kentucky Geography Network, Kentucky Division of Water and data files created by the authors specifically for this project.

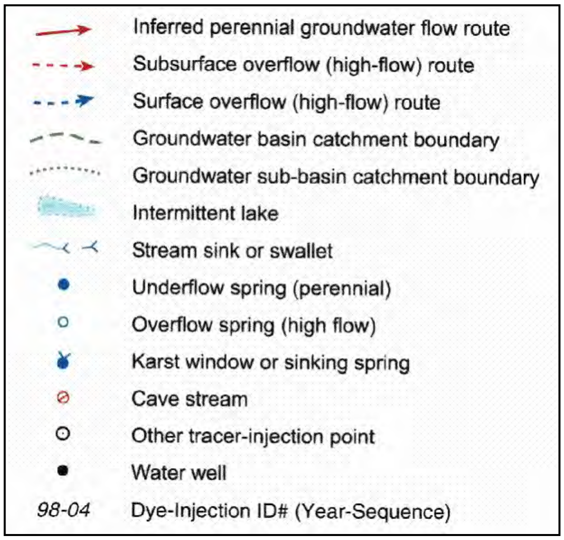

Figure 7. Karst Atlas Map Legend

Site Selection. Three main criteria were used to select sites for this project: 1) spring proximity to an impaired section of South Elkhorn Creek or one of its tributaries listed on the Kentucky 303d List of Waters; 2) access permission granted by the land owner and; 3) safety considerations while accessing the site.

Although this project was designed to assess groundwater quality, one of the secondary goals was to determine groundwater's influence on surface water quality. Therefore, springs draining directly to South Elkhorn Creek or one of its tributaries were given priority, especially for impaired reaches of surface streams. Site access permission and safety are a basic requirement of any successful project.

Because this study was designed to assess ambient groundwater conditions, those areas with known point-source discharges were eliminated from consideration. For example, sites affected by leaking underground storage tanks or landfills were not sampled as part of this study. Finally, special consideration was given to any site identified as a drinking water source. No public water suppliers in the study area use groundwater as a source, but three springs are currently used for domestic drinking water supplies. The listing of springs used specifically for this study can be found in Table 1.

A unique eight-digit identification number is used to catalog springs maintained in DEP's consolidated groundwater database. Springs selected for this study that were not in this database were inventoried and assigned an identification number. The inventory form notes specific details of the site such as location, owner information and spring description, along with other pertinent data. The data are entered into a DEP database, which is forwarded to the Groundwater Data Repository at the KGS. Site locations are plotted on 7.5 minute quadrangle maps maintained by the [former] Groundwater Branch and the forms are scanned and stored in a database as indexed electronic images.

Sample Collection Methods. Consistent with all DOW ambient groundwater monitoring efforts, samples of fresh, untreated groundwater were collected at each spring and analyzed for major inorganic ions; nutrients; bulk parameters (pH, conductivity, alkalinity, TDS and TSS); volatile organic compounds; total organic carbon; pesticides and dissolved and total recoverable metals. The analytical methods, containers, volumes collected, preservation methods and sample transport are consistent with DOW's Kentucky Ambient/Watershed Water Quality Monitoring Standard Operating Procedure Manual, prepared by the Water Quality Branch (2002c). Parameters to be measured, sample volume required for analysis, container type and preservation methods are shown on the attached Chain-of-Custody Form (Appendix B).

Major inorganic ions and bulk parameters are used to establish background groundwater chemistry and to measure impacts from nonpoint source pollutants such as abandoned mine lands and hydrocarbon production operations. Nutrients and total organic carbon are used to assess impacts from agricultural operations and improper sewage disposal. Pesticides are measured to determine impacts from agricultural, domestic and commercial use. Metals are useful to establish rock-groundwater chemistry, local and regional background levels and to determine nonpoint source impacts from active and abandoned mining operations. Volatile organic compound analyses determine impacts from urban run-off, oil and gas production and other point and nonpoint source impacts to groundwater.

Bacteria sampling was also conducted for this project. Analyses were performed by DOW biologists from the Water Quality Branch using the Colilert Quantitray© method. Bacteria are used to assess impacts from livestock and improper sewage disposal. However, the analytical methods used did not allow for specific source determination (human versus animal waste).

All chemical samples collected to meet grant commitments were analyzed by the Division of Environmental Services (DES) laboratory in accordance with applicable U.S. EPA methods. Additional data included in this study are from samples analyzed by ESB for other groundwater projects, as well as data from the KGS laboratory. Applicable U.S. EPA analytical methods were employed for all data used in this report.

Tracer Test Methods. Qualitative groundwater tracer tests, as described by Quinlan (1986) and Aley (1999), were conducted using three non-toxic fluorescent dyes. The names of dyes used in this study and the number of times each was injected are shown in Table 4.

As indicated by Schindel and others (1994) and Field and others (1995), these fluorescent dyes are optimal for use in groundwater-basin delineation because of non-toxicity, availability, analytical

Dyes Used	Trade Name	Color Index	Number of Injections
SRB (Sulforhodamine B)	Ricoamide Red XB	Acid Red 52	4
Eosine	15189 Eosine OJ	Acid Red 87	7
Uranine	Uranine Conc (Disodium Fluorescein)	Acid Yellow 73	6

Table 4. Fluorescent Dyes Used and Number of Injections

detectability, moderate cost, and ease of use. The quantity of fluorescent dye used for these tests was determined empirically based on several years of field experience. Prior to fieldwork, powdered dye was dissolved in water at a concentration of eight ounces per gallon. For uranine and eosine, this liquid-dye mixture was injected into active swallet sites at a rate of about one pint per mile of expected flow distance (equivalent to about one ounce of dry powdered dye per mile). Twice as much SRB dye was used for equivalent flow distances. Greater quantities of dye were used at dry sinkhole sites flushed with hauled water or during high-flow conditions.

Where tracers moved through monitored sites, fluorescent dyes were adsorbed and accumulated onto activated carbon samplers (dye receptors). In some cases, when the dye receptor was missing, the presence or absence of dye was determined directly by water samples. The carbon dye receptors were deployed in flowing water of springs, streams, and caves by use of a modified "gumdrop" anchor (Quinlan, 1986), or a brick fitted with a vinyl-clad copper wire and commercially available trot line clip for securing the receptors (Figure 8).

Background dye receptors were usually deployed, exchanged, and analyzed prior to dye injection in the study area. These background dye receptors served as controls for comparison with subsequently recovered receptors. In some cases background assessment was obtained from grab water samples in order to take advantage of unusual field opportunities to quickly inject dye. Dye receptors were typically exchanged weekly.

For analytical processing, samples of the retrieved carbon dye receptors were rinsed with tap water and eluted at room temperature for at least 15 minutes in a solution of 50% 1-propanol, 30% de-ionized water, and 20% ammonium hydroxide (NH_4OH). The eluted samples and water samples from this study were processed at the DOW's Groundwater Laboratory and analyzed for absence or presence and relative intensity of dye using a scanning spectrofluorophotometer. The DOW's Shimadzu RF-5301 PC instrument was purchased in 1998 and a computer sequence for analyzing dye samples was programmed by Peter Idstein, PhD candidate at Eastern Kentucky University. A macro to aid setup of the page printout, including site identification data, dye wavelength analyses, and scan specifications, was designed by Jack R. Moody. All printouts of dye analyses are archived in the Division of Water laboratory. Figure 9 shows a typical dye curve analyzed on the spectrofluorophotometer. The horizontal position of a dye peak indicates the fluorescence wavelength, which identifies the type of dye. The vertical height of the curve indicates the relative fluorescence intensity of the recovered dye and thus the qualitative confidence level of the positive dye recovery.

Positive dye recovery was determined when fluorescence intensity exceeded background by four times (4X). Dye-trace results were recorded on DOW Dye-Trace Record Forms. These documents include dye-injection site information and a detailed record of each dye receptor recovered during the study and are available upon request to the lead author.

The results of these investigations are discussed individually for each basin, and are listed under abbreviated dye-trace ID numbers such as 06-07 (Year - sequence of dye injection; the senior author was the principal investigator for all 16 tests). Analyzed dye-intensity level from recovered dye receptors is indicated by the following symbols, which represent the qualitative confidence level of a dye recovery and hydrologic connection:

– Negative result
? Inconclusive (< 4X background)
\+ Positive (> 4X background; < 1000 intensity units)
++ Very Positive (1000-10,000 intensity units)
+++ Extremely Positive (> 10,000 intensity units)

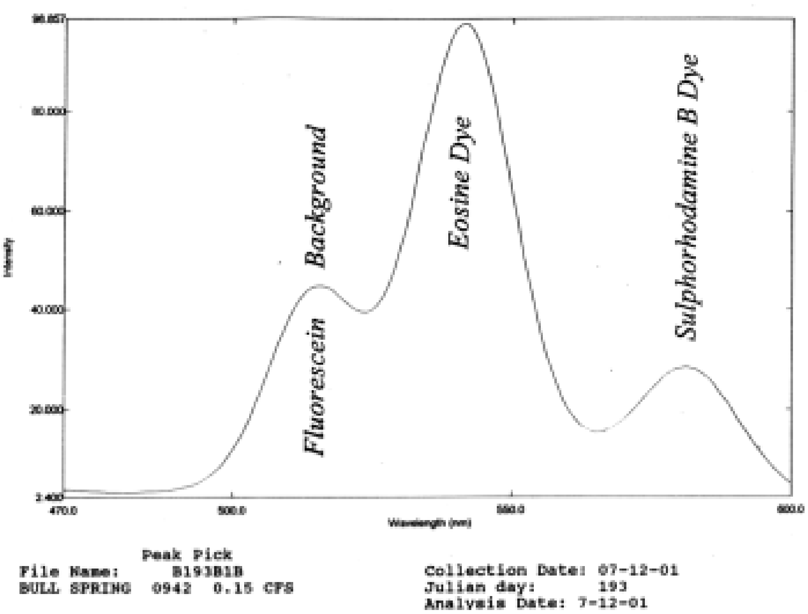

Figure 9. Typical Dye Curve on Spectrofluorophotometer

WATER QUALITY RESULTS and DISCUSSION

Introduction. Parameters used to assess groundwater for NPS impacts were divided into eight categories: bacteria (*E. coli*), bulk parameters, inorganic ions, metals, pesticides, residues, nutrients and volatile organic compounds. Individual parameters assessed in this report were chosen because they were common constituents found to be degrading surface stream reaches in the South Elkhorn Creek watershed, or proved to be NPS pollution indicators in previous research. Because the study area is completely within a single physiographic region and all springs discharge from the same stratigraphic unit (Lexington Limestone), the major controlling factor for significant variations in water chemistry is the land use practices in each spring's drainage area.

Bacteria (*E. coli*). *Escherichia coli* (*E. coli*) is a type of coliform bacterium present in the digestive tract of most warm-blooded animals and therefore is a good indicator of fecal contamination (USEPA, 2006). Fecal contamination of groundwater in a karst region can occur via livestock or pet excrement, or through the improper disposal of human waste infiltrating the subsurface through failing septic systems or leaking sewer lines. Due to the potential for rapid infiltration and high groundwater velocities in karst regions, contamination of this sort can be carried swiftly through the system with little or no natural attenuation. Most strains of *E. coli* are not harmful and merely serve as indicators of potential contamination, but some strains "…*produce a powerful toxin and can cause severe illness*" (USEPA, 2006).

E. coli values ranged from non-detection (or less than one colony-forming unit per 100 mL of water (CFU/100 mL) to greater than 2400 CFU/100 mL, with an overall median value of 170 CFU/100 mL. Springs draining residential areas had the highest median value at 185 CFU/100 mL, compared to those draining agricultural areas with a median value of 160 CFU/100 mL. The lowest median value was noted at Ms. Chandler Spring in Fayette County, which was 6 CFU/100 mL. This was followed closely by Water Cress Spring in Woodford County with a median value of 8 CFU/100 mL. Both of these springs drain agricultural areas. The highest individual median values occurred at Starns Milkhouse

Spring, Gano Spring and Hall Spring, all of which drain agricultural areas. Each of these springs had a median value greater than 2400 CFU/100 mL (NB: 2400 CFU/100 mL was the highest method detection limit without sample dilution). These springs were followed closely by McConnell Spring and Pisgah East Spring, both of which had a median value of 2400 CFU/100 mL and drain urban and agricultural areas, respectively. All springs failed to meet the drinking water standard for *E. coli* and only three springs met the standard for Primary Contact Recreation (Ms. Chandler, Water Cress and Waterford Springs). Both of these standards are based on the geometric mean of sample results and are discussed in-depth in the National Primary Drinking Water Standards (USEPA, 2006a) and 401 KAR 10:031, Section 7 (LRC, 2008). The map in Figure 10 shows a comparison of median *E. coli* values to the Primary Contact Recreation assessment for stream reaches. This map shows little correlation between the *E. coli* assessments for stream reaches and study area springs. The boxplots in Figure 11 show no significant difference in groundwater quality with respect to *E. coli* for the major land use types or sub-watersheds in the study area. *E. coli* values show wide variation between individual springs and sampling events. Definite NPS impacts to groundwater from bacteria are evident.

Several of the sampling events coincided with storm events, when spring discharges began to show response to increased runoff. These samples represent storm water runoff events and may reflect short-term contamination of groundwater from non-point sources (Ryan and Meiman, 1996).

Bulk Parameters. The bulk parameters assessed for this study include conductivity (or specific conductance) and pH. Both of these parameters were measured in the field during each sampling event using an Oakton PC10 field meter. Field measurements were verified with analyses by the ESB Laboratory.

Conductivity measures the ability of water (or any media) to conduct an electrical current. It is the inverse of a substance's resistance to an electrical current "*in ohms measured between opposite faces of a centimeter cube*" (Hem, 1985). Because conductivity is the inverse of resistance the results are sometimes reported as *mhos* (ohm backwards), but more often as Siemens, an equivalent term.

Conductivity values for fresh water are typically less than 1 siemen (or mho) and are reported as microsiemens (µS/cm) or micromhos (µmho) (USGS, 2007). Some laboratories report conductivity as "uU/cm", which is equivalent to microseimens and micrmhos such that uU/cm = µS/cm = µmho. Conductivity is considered a general indicator of water quality because it increases with increased amounts of ions dissolved in the water. However, this measurement does not differentiate between naturally-occurring dissolved ions from soil and rock and those attributable to NPS pollution, such as agricultural or urban runoff. No water quality standards are established for conductivity; however 800 µS/cm is roughly equal to 500 mg/L TDS (Hem, 1985), which is the SDWR standard for TDS set by the USEPA.

Conductivity in surface streams has been linked to taxonomic richness. Researchers have found a strong relationship between increased conductivity and population decreases in some aquatic species. The strongest influence on conductivity in the study area is bicarbonate, followed by chloride and sulfate. Carbonic acid is formed through the hydration of atmospheric CO_2. The carbonic acid dissociates to H^+ and bicarbonate (Ford and Williams, 1989). This is true of surface water and groundwater. This reaction allows for increased solubility of the carbonate minerals (i.e. calcite and dolomite) present in the karst aquifer, which provides another source of bicarbonate in the water discharging from springs.

Conductivity values for this study ranged from 290 to 1175 µS/cm, with a median value of 485 µS/cm for all 22 springs. Springs draining urban areas had the highest median value at 605 µS/cm. Springs draining agricultural areas had a median value of 426 µS/cm. The map in Figure 12 shows the median conductivity value for each spring. Although the springs draining urban areas had relatively high conductivity values, all median values for study area springs were below 800 µS/cm. Conductivity values display a fairly wide range, as seen in the boxplots (Figure 13). However, this seems to be due primarily to natural variability, with higher values related to storm events and increased turbidity. Webb and others (2000) report a median conductivity value of 552.5 µS/cm for groundwater in the Bluegrass Region and state that this most likely represents ambient groundwater conditions.

The relative acidity or alkalinity of water is reported as pH, which is "*the negative base-10 log of the hydrogen-ion activity in moles per liter*" (Hem, 1985). This is essentially the concentration of the hydronium ion, which is more easily expressed with logarithmic units than with the traditional milligrams per liter (mg/L) due to especially low concentrations. pH units are dimensionless and range from 0 to 14, with a pH of 7 being neutral. pH values below 7 are acidic and represent higher concentrations of hydronium ions, whereas values above 7 are alkaline and represent lower concentrations of hydronium ions. The pH of water can impact its overall quality with regards to its corrosivity, ability to dissolve materials, its taste and overall usefulness for industrial functions. The normal range of pH for aquatic systems is 6 to 9 (401 KAR 10:031) and the SDWR for drinking water, set by the U.S. EPA, is 6.5 to 8.5.

All pH values for this study were within the SDWR range of 6.5 to 8.5. Specifically, values ranged from 6.78 to 8.41 with an overall median value of 7.5. There is very little variation in median values between springs draining the various land-use types. Springs draining urban areas had a median pH value of 7.4 and those draining agricultural areas had a median value of 7.59. McConnell Spring, which drains an urban area, had the lowest median pH value at 7.28. Nuckols Cave Spring, which drains an agricultural area, had the highest median pH value at 8.01. Overall, pH values display a narrow range of natural variability (Figure 14) that fall within the SDWR range. This indicates ambient groundwater conditions rather than impacts from NPS pollution. The map in Figure 15 shows the median pH value for each spring.

Inorganic Ions. The major inorganic ions assessed for this study include chloride, fluoride and sulfate.

Chloride (Cl^-) is the most common ionic form of the element chlorine, accounting for approximately 75% of all chlorine in the earth's crust, atmosphere and hydrosphere. Chloride occurs naturally in rocks and soil, especially from evaporites such as halite. Thus, all natural waters contain chloride, though typically in small amounts (Hem, 1985). Chloride also occurs in sewage, industrial brines and in urban runoff from road salt application. Naturally-occurring chlorides associated with brines from oil production can contaminate aquifers if oil wells are improperly constructed or abandoned or if these brines are not properly disposed, but this is not an issue in the study area.

Chloride values in this study ranged from 2.51 mg/L to 189 mg/L with a median value of 20.3 mg/L. Chloride was detected in all 237 samples analyzed for this study. Of these 237 analyses, 234 (99%) were less than half the SDWR of 250 mg/L and no samples exceeded the SDWR. Springs draining agricultural areas had a median chloride value of 9.67 mg/L, which is considerably lower than the median value of 42.8 mg/L for those draining urban areas. A scatter plot of the chloride data shows occasional spikes in chloride levels during the winter months, which may be attributable to runoff following road salt application. However, these spikes are rare and also occur during non-winter months when road salt application would not be expected. Although it should be noted that the highest spikes in chloride values did occur during winter months. Another potential source for higher chlorides found in urban springs is leaking sewers. Please refer back to the Land Cover and Land Use section for specific details of documented groundwater contamination from sewers in the South Elkhorn Creek watershed. These data point toward potential NPS impacts to groundwater from chlorides in urban areas. The boxplots (Figure 16) show a much wider range and a higher median value associated with springs draining urban/residential areas. Because median chloride values at individual springs were so low no map is presented.

Fluoride occurs naturally in groundwater through the dissolution of rocks containing fluoride minerals, such as fluorite (CaF_2). Fluoride also enters the environment through atmospheric deposition of hydrogen fluoride from coal-fired power plants and manufacturing processes. Because small amounts of fluoride [1 part per million (ppm)] in water help prevent tooth decay, public water systems often add it to their water. Some researchers claim this practice is potentially harmful and therefore the efficacy of drinking water fluoridation is a widely debated issue. The MCL for fluoride is 4 mg/L (and the SDWR for fluoride is 2 mg/L). Exposure to excessive amounts of fluoride can result in dental and skeletal fluorosis. Brittle, mottled and discolored tooth enamel characterizes dental fluorosis. Skeleton fluorosis causes a wide range of muscle and bone problems, including osteoporosis (O'dell and others, 2006).

Fluoride was detected in 236 of 237 samples analyzed for this study. The median value for fluoride was 0.196 mg/L. The median value was slightly higher in springs draining urban areas (0.2 mg/L) than those draining agricultural areas (0.191 mg/L). However, all detections were less than half of the MCL of 4 mg/L. Because median fluoride values at individual springs were so low, no map or boxplots are presented. The narrow range of values shows natural variation and does not indicate impacts to groundwater from nonpoint source pollution.

Sulfate (SO_4) occurs naturally in groundwater via weathering of sulfate and sulfide minerals, such as gypsum, anhydrite or pyrite. Sulfate is common in groundwater of the study area and therefore is not considered a good indicator of nonpoint source pollution. Anthropogenic sources of sulfate include combustion of fuels and ore smelting. The SDWR for sulfate is 250 mg/L. Higher concentrations may impart undesirable odor and taste and can have a laxative effect.

Sulfate was detected in all 237 samples analyzed for this project, with a median value of 24.0 mg/L. The maximum concentration of 80.8 mg/L and the highest median value for sulfate occurred in springs draining urban areas of Fayette County. More specifically, the median sulfate value for urban area springs was more than twice that of springs draining agricultural areas. This may indicate nonpoint source impacts to groundwater from sulfate in urban areas. However, all detections were well below the SDWR and are not considered problematic. Because median sulfate values at individual springs were so low no map or boxplots are presented.

Metals. Properties such as low pH and high dissolved oxygen content in water increase the potential for dissolution of metals. Urban runoff, mining, land farming of sewage and other wastes, coal-fired power plant emissions and industrial operations can produce nonpoint sources of metals pollution. Interpretation of metal concentrations in groundwater can be problematic. Increased metal concentrations can originate from point and nonpoint sources, or may be naturally occurring. For this report, data for arsenic, barium, iron, lead, manganese and mercury were reviewed.

All samples collected for this study were analyzed for total and dissolved metals. Because the drinking water MCLs and SDWRs are based on total metal concentrations rather than dissolved metals, only total metals values were reviewed.

All of the metals analyzed for this study can occur naturally in groundwater through the weathering of rocks and soil. Thus, they are generally poor indicators of NPS pollution. Statistical analyses of metals results show that the median value for each metal was either extremely low or "non-detect". The data, coupled with the absence of any suspected nonpoint sources for metals in the study area, are indicative of ambient groundwater conditions.

Pesticides. Historically, five major pesticides have been included in groundwater quality assessments for NPS pollution conducted by the [former] Groundwater Branch: atrazine, metolachlor, cyanazine, simazine and alachlor. These particular pesticides were chosen based on sales data, which showed that they were the most commonly used pesticides. However, due to the number and nature of pesticide detections for this project, a different approach was used.

Pesticides (including herbicides and fungicides) are not naturally-occurring chemicals. Therefore, their presence in groundwater samples is indicative of some degree of contamination. Due to the extremely low-level pesticide detections noted in study area springs, this review considered all pesticides detected.

During the study period there were a total of 207 detections of 48 unique pesticides at 21 of the 22 study area springs. No pesticides were detected above their respective water quality standards. Gano Spring in Scott County was the only sample site with no pesticide detections. The ESB Laboratory analyzed for 123 unique pesticides in each sample. This yields a total of 30,068 pesticide analyses.

Therefore, the 207 detections represent a detection rate of approximately 1%. Atrazine was the most frequently detected pesticide with 52 detections. Most notable is that the majority of pesticide detections occurred in springs draining urban/residential areas (112 or 54%). In particular, McConnell Spring in downtown Lexington comprised 62 pesticide detections (30%). (NB: *Data for McConnell Spring included historical samples collected prior to this project dating back to 1995. The total number of pesticide detections at McConnell Spring is 139.)*

The data clearly show NPS impacts to groundwater from pesticides. However, because all detections were in trace amounts, the degree of degradation is unclear. The map in Figure 17 shows the distribution of study area springs and the range of unique pesticides detected at each.

Residues. Total dissolved solids (TDS) and total suspended solids (TSS) are the residues assessed for this study.

TDS analysis measures the residue remaining from a water sample following filtration through a 1.5 µm filter and evaporation of the sample in an oven at 180º C. The remaining residue represents the TDS (in mg/L) in the original sample (Todd Adams, DES Lab, oral comm., 2008). TDS measurement may provide a general indication of water quality. However, because individual parameters are not identified, its usefulness for this purpose is limited. The SDWR for TDS is 500 mg/L; higher levels may impart unacceptable taste or odor. TDS were detected in all 238 sample analyses for this study. TDS values ranged from 102 mg/L to 872 mg/L. The median value for TDS was 286 mg/L and none of the sample sites had a median value above the SDWR. However, there were four TDS detections that exceeded the SDWR. All four of these detections were at McConnell Spring. Springs draining urban and residential areas show a higher median value than those draining agricultural areas. TDS values seem to fall in a normal range of variation and are not considered indicative of NPS impacts. The map in Figure 18 shows the distribution of median TDS values.

TSS analysis measures the residue captured by a 1.5 µm filter after drying the filter to a constant weight in an oven at 103º C. The difference in filter weight between pre- and post-filtration represents the TSS (in mg/L) in the original sample (Todd Adams, DES Lab, oral comm.., 2008). Runoff from industrial, agricultural or urban areas can suspend solids and carry them into groundwater systems via stream swallets and sinkholes. Elevated TSS can "…*reduce water clarity, degrade habitats, clog fish gills, decrease photosynthetic activity and cause an increase in water temperature*" (MMSD, 2002). No drinking water standard exists for TSS. The comparison value for data in this report is 35 mg/L, the KPDES surface water discharge permit requirement for sewage treatment plants.

TSS values for study area springs ranged from non-detect to 102 mg/L. TSS were detected in 145 of 243 (60%) samples analyzed for this project. TSS values ranged from non-detect to 102 mg/L, with a median value of 2.5 mg/L. The median TSS values compared by land use type were equivalent at 2.5 mg/L. The highest one-time TSS detection came from a spring draining agricultural areas. Median TSS values in the middle and lower sections of the watershed, which are mainly agricultural areas, were considerably higher than those in the headwaters. None of the median TSS values for individual springs exceeded the KPDES standard. In karst systems TSS can vary rapidly with flow. Increased surface runoff infiltration into sinkholes and stream swallets can capture and carry a significant amount of sediment into the subsurface drainage and remobilize sediments previously deposited in the system. This causes a corresponding increase in turbidity and TSS in water eventually discharged at a spring. Therefore, occasional TSS spikes indicate NPS pollution that may be linked to poor agricultural management practices. The map in Figure 19 shows the distribution of median TSS values.

Nutrients. The nutrients assessed for this study include ammonia (as N), nitrate (as N), nitrite (as N), orthophosphate (as P) and total phosphorus. All of these nutrients occur naturally in the environment, and also have anthropogenic sources. Excessive nutrient enrichment of surface water, or eutrophication, can lead to excessive plant growth. This is problematic because the explosion of plant growth and their eventual death and decay can reduce the amount of dissolved oxygen available to aquatic animal life (USGS, 2008).

Ammonia (NH_3) occurs naturally through the decay of organic matter, such as plants and animal waste. The main anthropogenic source of ammonia found in groundwater is from ammonia-based fertilizers. The U.S. EPA does not have a drinking water standard for ammonia-N; however, the proposed DEP limit for groundwater is 0.11 mg/L.

Ammonia-N was detected in 16 of 217 samples (7%) analyzed for this study. The median ammonia-N value was "non-detect" at the 0.05 mg/L detection limit. Only one sample exceeded the DEP standard of 0.11 mg/L: McConnell Spring in Fayette County, which drains an urban/residential area. Extreme outliers observed in the boxplots (Figure 20) may be indicative of NPS pollution; however, the majority of results seem to show no impacts. All median values for individual springs were below the detection limit and there is little variation between land use types.

Nitrate (NO_3) occurs in the environment through various natural and man-made sources: decomposing organic matter, nitrogen-fixing plants, human and animal waste, nitrogen fertilizers and atmospheric deposition from combustion. In this report nitrate is reported as the equivalent molecular nitrogen (nitrate-N). The drinking water MCL for nitrate-N is 10 mg/L. Carey and others (1993) reported background nitrate-N levels of about 1 mg/L in groundwater in the Bluegrass area of Kentucky.

The health risk most commonly associated with excess nitrate consumption is methemoglobinemia, or "blue-baby" syndrome, in infants. Potential impacts to adults are being studied. Nitrate removal by ordinary water treatment methods is difficult, making its occurrence above the MCL problematic.

Nitrate-N was detected in all 216 of the samples analyzed for this report. Study area springs show a wide range of nitrate-N levels. The minimum level was 0.793 mg/L and the maximum was 28.2 mg/L, with a median of 4.05 mg/L. Springs draining agricultural areas had the highest median value of

5.14 mg/L. The median level in springs draining urban/residential areas was not significantly lower at 3.4 mg/L. A total of 12 samples from 4 springs exceeded the drinking water standard of 10 mg/L. Results for Viper Spring, which drains an agricultural area of Scott County, show concentrations consistently over the MCL. NPS impacts to groundwater are evident based on the number of detections above the MCL and median values in both land use types that exceed background nitrate-N levels (Figure 21). The map in Figure 22 shows the distribution of median nitrate-N values for each monitored spring.

Nitrite (NO_2) occurs naturally in the environment from many of the same sources as nitrate. However, nitrite is unstable and tends to quickly convert to nitrate through oxidation. Nitrite-N was detected in 39 of 216 samples (18%) and all detections were well below the MCL of 1 mg/L. The maximum concentration of nitrite-N detected was 0.038 mg/L and the median value was "non-detect" at the 0.02 mg/L detection limit. The data indicate that nitrite-N is not a significant NPS pollutant, although it may contribute to nitrate levels.

Orthophosphate-P (or ortho-P) is the final product of the dissociation of phosphoric acid (H_3PO_4). Ortho-P occurs naturally through organic decomposition and from phosphate minerals, such as apatite, found in phosphatic limestone. Anthropogenic sources of ortho-P include concentrated animal waste, detergents, some organic pesticides and fertilizers. Ortho-P does not have a drinking water standard. The comparison value used for this study is 0.18 mg/L, which was the median ortho-P value for groundwater in the Bluegrass Region reported by Webb and others (2004).

Ortho-P was detected in 207 of 216 samples (96%) analyzed for this report. The median value for ortho-P in study area springs was 0.23 mg/L. Springs draining agricultural areas had a median value of 0.2 mg/L. Springs draining residential areas had a median value of 0.26 mg/L. The boxplots in Figure 23 show little difference between land use types relative to ortho-P concentrations. The map in Figure 24 shows that median values for about half of the study area springs were below the reference value of 0.18 mg/L. Though not widespread, NPS impacts to groundwater from ortho-P are evident.

Total phosphorus is the sum of organic and inorganic phosphorus with sources similar to ortho-P. Total phosphorus was detected in all 224 samples analyzed for this report. Total phosphorus does not have a drinking water standard so results were compared to the TMDL standard of 0.3 mg/L for surface water in the Bluegrass Region. The median value for total phosphorus was 0.32 mg/L. There was little variation between median values based on land-use type. Springs draining agricultural areas had a median value of 0.34 mg/L, while those draining urban/residential areas had a median value of 0.31 mg/L. The boxplots in Figure 25 show relatively narrow value ranges regardless of site groupings and median values that are almost consistently over the TMDL standard. The map in Figure 26 shows that a little more than half of the study area springs had individual median values over the TMDL standard of 0.3 mg/L. Based on the map, land use imparts little variation on total phosphorus values. The data point to definite NPS impacts to groundwater.

Volatile Organic Compounds. The volatile organic compounds (VOC) assessed for this report include benzene, toluene, ethylbenzene and total xylenes (BTEX), as well as methyl-tertiary-butyl-ether (MTBE). The BTEX compounds represent those volatile organics most often detected in groundwater. These compounds are included here because they are some of the most commonly-detected hazardous components of gasoline and their potential acute and long-term impacts to human life and aquatic health (Irwin and others, 1997). MTBE is of concern due to its toxicity, but has rarely been detected in groundwater in Kentucky.

BTEX compounds do occur naturally in the environment. However, most impacts to groundwater commonly occur from point sources, such as leaking storage tanks and large fuel spills. In urban areas, nonpoint sources of BTEX and MTBE include leaks from automobile gas tanks. Some researchers are concerned with possible airborne deposition of BTEX and MTBE from the incomplete combustion of fossil fuels. An additional potential source of BTEX is from pesticides that may contain VOCs, which are used as carriers for the active ingredient. These VOCs are important to evaluate because of their widespread use and their various detrimental effects to human health and the environment.

BTEX and MTBE are persistent in the environment, particularly in groundwater, for two primary reasons. First, water solubility of BTEX is moderate to high, ranging from a low of 161 mg/L for ethylbenzene to 1730 mg/L for benzene. In comparison, MTBE is very soluble, with values from 43,000 mg/L to 54,300 mg/L. Because of this solubility, MTBE in contaminant plumes moves at virtually the same rate as the water itself, whereas BTEX plumes move at somewhat slower rates. Second, because these compounds (except for benzene) have relatively low vapor pressure and Henry's law constants, they tend to remain in solution, rather than being volatilized.

Because of these and other, physical and chemical characteristics, clean-up of BTEX and MTBE contaminated groundwater is difficult. "Pump and treat" and various bioremediation techniques have proven the most useful (O'Dell and others, 2006).

Benzene is found naturally in the environment in organic matter, including coal and petroleum and is released into the environment during combustion. Benzene is also found in products manufactured from crude oil, including gasoline, diesel and other fuels, plastics, detergents and pesticides. Benzene is also produced during the combustion of wood and vegetation. Benzene is a known carcinogen in humans and has been associated with various nervous system disorders, anemia and immune system depression (U.S. EPA, 2006a). The MCL for benzene is 0.005 mg/L. Benzene was detected in only 2 samples in this study - both from McConnell Spring - therefore no map or boxplots were prepared.

Toluene is a clear liquid that occurs naturally in crude oil, as well as in refined oil products, such as gasoline. Toluene also occurs naturally in coal and is common in paints, paint thinner, fingernail polish and other products. Although toluene is not listed as carcinogenic in humans (U.S. EPA, 2006a), it has been linked to several detrimental physical and neurological effects that include diminished coordination and the loss of sleep ability. Toluene has an MCL of 1.0 mg/L. In this study, toluene was detected in 3 out of 203 samples, therefore no map or boxplots were created. The samples with detections were collected at McConnell Spring and were well below the MCL.

Ethylbenzene is a component of crude oil and is a constituent of refined petroleum products, including gasoline. In addition, this colorless liquid is used to manufacture styrene. According to the U.S. EPA (2006a), limited studies of ethylbenzene have shown no carcinogenic effects in humans; however, animal studies have shown detrimental health effects to the central nervous system. The MCL for ethylbenzene is 0.7 mg/L. Ethylbenzene was not detected in this study therefore no map or boxplots are presented.

Xylenes are any one of a group of organic compounds typically found in crude oil, as well as in refined petroleum products such as gasoline. Xylenes are clear and sweet-smelling. They are used as solvents and in the manufacture of plastics, polyester and film. Total xylenes have an MCL of 10 mg/L. They are not carcinogenic to humans, although data are limited. In humans, exposure to excessive amounts is associated with disorders of the central nervous system, kidneys and liver (U.S. EPA, 2006a). Xylenes were detected 6 times in 202 analyses during this study. Again, neither a map nor boxplots are presented. All of these detections were at McConnell Spring and were below the MCL.

Methyl-tertiary-butyl-ether, or MTBE, is a man-made compound and does not occur naturally. It is added to gasoline as an oxygenate to promote more complete combustion, increase octane and to reduce emissions of carbon monoxide and ozone. MTBE is very mobile in groundwater and has contaminated numerous aquifers throughout the United States. This compound has no MCL; however, the US EPA Regional Screening Level (RSL) is 0.012 mg/L. According to the U.S. EPA (1997), no studies have documented human health effects from the consumption of MTBE-contaminated water. However, animal studies have shown some carcinogenic and non-carcinogenic effects.

Seven samples in 201 analyses detected MTBE; all of these occurred at McConnell Spring. One of these detections exceeded the RSL. Because MTBE was detected at only one sample site no boxplots or map are presented.

Overall BTEX and MTBE were not recognized as major pollutants in this study. However, they occurred at only one spring, multiple detections of BTEX and MTBE at McConnell Spring does indicate localized impacts to groundwater from these compounds. These impacts may be due to minor point source releases and leaks that are common in urban areas.

TRACER TEST RESULTS

Previous Tracer Tests. Numerous investigators have conducted tracer tests within and adjacent to South Elkhorn Creek basin. Karst groundwater data derived from these and other reports have been compiled by Currens and others (2002) as part of the Kentucky Karst Atlas Map series. Combined, these authors have identified 90 unique subsurface flow paths and delineated a total of 18 karst groundwater basins that intersect the South Elkhorn Creek watershed.

The earliest work was performed by Jillson (1945) in the Roaring Spring groundwater basin. In doing this Jillson helped pioneer karst groundwater investigation in Kentucky and delineated the central course of Roaring Spring's groundwater flow. This was followed by a period of relative inactivity (in South Elkhorn Creek's basin) until the late 1970s when researchers from the University of Kentucky began extensive investigations of the Inner Bluegrass karst region of Kentucky. McCann (1978) expanded on Jillson's work in Roaring Spring basin, further refining its groundwater basin boundary, as well as beginning work on previously untraced springs. Spangler (1982) conducted 75 original dye injections, mostly in the area between North and South Elkhorn creeks. This was followed by Thrailkill and others (1982) who continued work on several noteworthy spring basins, including Steeles Spring, Lindsay Spring and Silver Spring, among others. Spangler also conducted additional tracer tests on numerous springs throughout the 1980s and 1990s, which include: Silver Spring, Lindsay Spring, Nance

Spring, Santen Spring, Slacks Spring and Gano Spring (Thrailkill and others,1982); Prestons Cave (McConnell) Spring, Garrett's Spring, Cave Hill Spring, Kentons Bluehole and Hall Spring as well as other minor springs (Currens and others, 2002 and 2003).

Karst investigations continued through the 1990s and early 2000s with tracer tests conducted by Ray and others at Cedar Cove Spring and Roaring Spring (Currens and others, 2002), as well as Currens and Graham at Mathews Spring, Drive-In Spring and Polley Spring (Currens and others, 2003). The most recent previous investigations were conducted by Paylor and Currens (2001) and Paylor (Currens and others, 2002). These tracer tests identified all or portions of the catchment areas for Pisgah [East] Spring, Fishing Shack Spring and Fawn Leap Spring. Paylor and Currens (2001) also used their data and those obtained from previous work to determine the *normalized base-flow* (or Unit Base-flow – UBF) for the Inner Bluegrass karst region. As discussed earlier in this paper, they calculated the UBF for Inner Bluegrass springs at 0.03 $ft^3/s/mi^2$. The map showing these previous tracer tests is presented in Figure 27 (Currens and others, 2002).

Waterford Spring. No record of previous dye-tracing for Waterford Spring could be found in the literature. However, this spring was referenced and mapped by Thrailkill and others (1982). In that study the spring is referred to by the land owner's name as Wests Spring. Based on seven spring flow estimates, Thrailkill and others placed its median discharge in the 30 to 100 liters per second (1.0 to 3.5 ft^3/s) range. This spring discharges as a bluehole from a near-vertical conduit approximately three feet in diameter at the base of a hill. The spring has been developed to supply water for domestic and livestock use. The base-flow measurement for Waterford Spring made by the lead author of this study was 0.12 ft^3/s, which yields an approximate basin area of 4 mi^2, applying the Inner Bluegrass UBF of 0.03 $ft^3/s/mi^2$ (Paylor and Currens, 2001). However, based on the two recovered traces at this spring, only 2.5 mi^2 of basin area can be identified. It is unknown whether the spring's base-flow measurement is erroneous or if there is anomalously high groundwater storage in the basin. Field reconnaissance revealed potential dye injection points that may clear up this discrepancy, but hydrologic conditions (drought 2007) precluded further study prior to the writing of this report.

Trace # 06-11: Cabin Swallet to Waterford Spring. This swallet is located on Three Chimneys Farm, north of Old Frankfort Pike and approximately 3500 feet northwest of its intersection with Big Sink Road. On August 25, 2006 one-quarter ounce of uranine was injected into this active swallet draining the overflow from a spring-fed pond. Flow into the swallet was estimated to be 0.01 ft^3/s. Four days later, on August 29, Waterford Spring was extremely positive for uranine dye. Uranine dye was detected at Waterford Spring for 24 days following the injection. The inferred distance of this trace is 7337 feet, with an inferred groundwater velocity greater than 1834 ft/day.

Trace # 06-14: Three Chimneys Sink to Waterford Spring. This is a free-draining sinkhole located on the west side of Big Sink Road, approximately 3500 feet south of its intersection with Old Frankfort Pike. On September 26, 2006 five ounces of SRB were injected into this sinkhole using 200 gallons of hauled flush water. This trace was a replication of #06-09, which was conducted approximately one month earlier and never recovered. Sixteen days later, on October 12, Waterford Spring was very positive for SRB. Two subsequent analyses both yielded negative results for SRB. This does not meet the minimum criterion of two sequential dye recoveries. However, it is assumed that groundwater flow was highly efficient and all dye had passed through the spring prior to the first dye receptor exchange. The inferred distance of this trace is 12,290 feet, with an inferred groundwater velocity of greater than 774 ft/day. Please refer to Figure 28 to view the map of the two traces discussed.

Spring Station Spring (Roaring Spring basin). As discussed, significant dye-tracing has been conducted within Roaring Spring basin and its recharge boundary has been delineated. Due to ease of access, Spring Station Spring was chosen as the monitoring site within Roaring Spring basin, for dye-tracing as well as water quality. Spring Station Spring discharges as a bluehole approximately 15 feet wide at the base of a small limestone bluff. The base-flow measurement for Spring Station Spring is 0.5 ft^3/s (KDOW Consolidated Groundwater Database) and its basin area is approximately 16 mi^2 (modified from Currens and others, 2002). Three traces were recovered at Spring Station Spring. All three of these dye injections originated near the eastern divide and it was hypothesized that they may redefine the groundwater basin boundary. However, this was not the case as they merely reinforced the basin boundary determined through earlier research.

Trace # 06-04: Hedden Swallet to Spring Station Spring. Hedden Swallet is located on the former Hedden Farm, approximately 3 miles south of Midway. The swallet lies in a large sinkhole on the northeast quadrant of the cryptoexplosive structure site just outside of Versailles, Kentucky. The swallet catches the overflow from a series of small ponds that are fed by an intermittent spring. On April 18, 2006 two ounces of SRB were introduced into this swallet with a natural flow of water that was estimated to be 0.01 ft^3/s. This flow was approximately doubled for 10 minutes by forcing the overflow pipe from the pond deeper into the water. Six days later, on April 24, Spring Station Spring was positive for SRB. Spring Station Spring was still positive for SRB thirteen days later. The inferred distance of this trace was 27,623 feet with an inferred groundwater velocity greater than 4,604 ft/day.

Trace # 06-05: Williams Lane Swallet to Spring Station Spring. This swallet is located just north of Williams Lane in the Big Sink area northeast of Versailles. On April 18, 2006 five ounces of eosine were poured into this active swallet with a natural flow of water estimated at 0.05 ft^3/s. Analysis six days later, on April 24, showed that Spring Station Spring was very positive for eosine. The spring was still positive 13 days after injection. This trace had an inferred distance of 38,152 feet. This trace had the fastest inferred groundwater velocity, which was greater than 6,403 ft/day.

Trace # 06-07: Ashview Swallet to Spring Station Spring. This swallet is formed by a sinking spring in a large sinkhole on the Ashview Farm property south of Paynes Mill Road, just east of Versailles. Two ounces of SRB were injected into this swallet with a natural flow of water estimated to be 0.05 ft^3/s on April 15, 2007. One week later, on April 22, Spring Station Spring was positive for SRB. This trace had the longest inferred distance at 42,805 feet and had a groundwater velocity greater than 6,115 ft/day. This swallet is approximately 1,000 feet west of an injection point used by Paylor (Currens and others, 2002) that was shown to drain to the east to Pisgah East Spring. These two injection points are on either side of the Roaring Spring basin boundary and clearly define it at that point. Please refer to Figure 29 which shows a map of the traces discussed as well as those from previous investigations.

Elkdale Spring. One previous tracer test was attempted at this spring prior to this study. However, the principal investigator of that trace suggested that those results were questionable and that it should be replicated if possible. The attempted replications of that trace are discussed later in the "Non-recovered Traces" section of this report.

Elkdale Spring issues from a bedding plane separation in a small spring house situated in the bottom of a broad valley. The spring is located north of Paynes Mill Road roughly 3,000 feet west of the Woodford County-Fayette County line. Base-flow discharge is estimated to be 0.1 ft^3/s. Due to access restrictions the spring was monitored approximately 3,400 feet down the spring run, just above its confluence with South Elkhorn Creek.

Trace # 06-06: Slick Falls Swallet to Elkdale Spring. Slick Falls swallet is located on the Winstar Farm property, approximately 200 feet west of Pisgah Pike. During the wet season the swallet drains overflow from the two large ponds above it. On May 15, 2006 two ounces of eosine were injected into this swallet with a natural flow of 0.1 ft^3/s. Seven days later Elkdale Spring was extremely positive for eosine. Four subsequent analyses, up to one month later, showed that Elkdale Spring was still positive for eosine. The inferred distance of this trace was 5,011 feet with an inferred groundwater velocity greater than 725 ft/day. Figure 30 shows a map of the results for this tracer test.

Fawn Leap Spring. Fawn Leap Spring discharges at the base of a hill from within a covered spring box and its orifice cannot be seen. The spring has been developed and was used extensively for domestic and livestock water supplies on Fawn Leap Farm until the 1990s. Anecdotal information received during field reconnaissance indicated that this spring may have supplied water to the town of Midway when it was first settled. Fawn Leap Spring is referenced by Thrailkill and others (1982) and is called Cogar Spring, named for the previous land owner. They place its median discharge in the 1 to 3 liters per second (0.04

to 0.11 ft^3/s) range, which agrees with the base-flow measurement of 0.15 ft^3/s made for this study. However, no traces were recovered at this spring in Thrailkill's study. The only documented dye recovery at Fawn Leap Spring prior to the current study was conducted by Paylor (Currens and others, 2002) from a swallet approximately 1 mile to the southwest. Similar to Waterford Spring, the current and previous tracer data identify a basin area of approximately 2.5 mi^2. However, applying the Inner Bluegrass UBF of 0.03 $ft^3/s/mi^2$ (Paylor and Currens, 2001) to the authors' base-flow measurement yields an estimated basin area of 5 mi^2. Again, the source of this discrepancy is unclear.

Trace # 07-03: This was one of the most interesting tracer tests conducted for this study. On March 16, 2007 one ounce of uranine was injected into South Nuckols Swallet. This swallet, fed by an intermittent sinking spring, is located below a small bridge on Spring Station Road about 1.5 miles west of Midway on the Nuckols Farm. Five days later, on March 21, Nuckols Overflow Spring, Nuckols I-64 Spring and Box & House Spring (north of injection point) were extremely postive for uranine. That same day Fawn Leap Spring was very positive for uranine (southeast of injection point). The trace had bifurcated with the main groundwater flow direction to the north and a minor component to the southeast. Please refer to Table 5 for inferred groundwater flow path distances and velocities associated with this trace.

Table 5. Results of Trace # 07-03

Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
So Nuckols Swallet	Uranine 3/16/07 07-03	1 oz	0.05	No	Fawn Leap Sp (++) Nuckols OF Sp (+++) Nuckols I-64 Sp (+++) Box & House Sp (+++) 3/21/07	7714 5134 5688 6952	> 1596 > 1053 > 1147 > 1402

Trace # 07-04: Due to the potential for interference by background uranine and the relatively weaker recovery at Fawn Leap Spring the authors decided to replicate trace # 07-03. The replication was conducted with eosine to ensure that the previous recovery at Fawn Leap Spring was not a false positive. For this trace three ounces of eosine were injected into the swallet on October 24, 2007, following a significant rain event. Five days later, on October 29, analysis of the dye receptor at Fawn Leap Spring showed inconclusive results. There was a definite detection of eosine, but the intensity was only 2.5 times that found in the background analysis. A second analysis two days later showed the same results. Neither of these analyses met the positive recovery criterion of 4 times background dye intensity. However, based on these data and those of the original trace, the authors determined that a definite hydrologic connection exists between South Nuckols Swallet and Fawn Leap Spring. Because flow into the swallet is intermittent and tracer tests revealed a weak connection, this groundwater flow route is considered to be a subsurface overflow to Fawn Leap Spring.

Trace # 07-05: Hurstland Sinking Spring to Fawn Leap Spring. Hurstland Sinking Spring is a small, wet weather spring that discharges just below the rim of a large sinkhole. The largest discharge observed at this sinking spring was less than 0.05 ft^3/s. The spring flow runs down slope within the sinkhole approximately 50 horizontal feet then disperses and percolates into the soil, approximately 15 vertical feet above the bottom of the sinkhole. No discreet swallow hole could be located. On December 14, 2007, following significant rain, 5 ounces of uranine were trickled into the spring run at the lowest point where flow was observed. Within 30 minutes most of the dye had seeped into the soil and was no longer visible on the surface. Three days later, on December 17, Fawn Leap Spring was extremely positive for uranine dye. Subsequent analysis on December 19 revealed that Fawn Leap Spring was still very positive for uranine. This trace has an inferred groundwater flow path of 6,900 feet and an inferred groundwater velocity greater than 2,379 ft/day. This positive recovery provides further evidence of the subsurface overflow interpretation of trace numbers 07-03 and 07-04. Please refer to Figure 31 to view the map of these tracer test results.

Box & House Spring. Box & House Spring is located about two miles northwest of Midway just south of US Highway 421 on the Nuckols Farm. This spring discharges from a small spring box and then flows through a spring house before entering a small unnamed tributary to South Elkhorn Creek. During base-flow conditions Box & House Spring forms the headwaters of this unnamed tributary. A small house, made of limestone block similar to the spring house, is situated on the hillside above the spring. These buildings were reported as the original farm settlement dating to the late 1700s, when the area was first settled. No reference to this spring could be located in previous investigations. The estimated base-flow for this spring was 0.05 ft^3/s and the delineated basin area is 1.5 mi^2. This yields a UBF of 0.033 $ft^3/s/mi^2$, which conforms to the assessment made by Paylor and Currens (2001).

Trace # 07-01: Nuckols Cave swallet to Box & House Spring and Nuckols I-64 Spring. Nuckols Cave Spring discharges to a large pond that overflows directly into a swallow hole. The cave and swallet are approximately 0.5 mile south of Box & House Spring. During excessively wet periods this swallet becomes inundated, causing overland run-off. On January 24, 2007 two ounces of eosine were injected into this swallet with a natural flow of approximately 0.15 ft^3/s. Two days later, on January 26, Box & House Spring and Nuckols I-64 Spring were both positive for eosine. A second set of analyses seven days after injection showed inconclusive results at Box & House Spring and negative results at Nuckols I-64 Spring. Although Nuckols Overflow Spring was discharging considerably more water than either Box & House Spring or Nuckols I-64 Spring, no eosine was recovered from it. The portion of this trace that went to Box & House Spring had an inferred groundwater flow path of 2740 feet with an inferred groundwater velocity greater than 1,400 ft/day. The inferred groundwater flow path to Nuckols I-64 Spring was 1,463 feet, with an inferred groundwater velocity greater than 747 ft/day.

Trace # 07-03: Please refer to the previous discussion of this tracer test under Fawn Leap Spring for specific details. This trace was recovered at Box & House Spring, Nuckols I-64 Spring and Nuckols Overflow Spring. The inferred flow path from this trace passes just to the east of Nuckols Cave Spring and its swallet. However, it is noteworthy that this trace was not detected at Nuckols Cave Spring which is the largest spring feature in the general area. Please refer to Figure 31 to view the map of these tracer test results.

B. Riddle Spring. B. Riddle Spring is located approximately 0.75 mile downstream of the Fishers Mill bridge on the Scott County side of South Elkhorn Creek. The spring discharges from a bedding plane within a spring box, situated along the bank of an unnamed tributary to South Elkhorn Creek just upstream from their confluence. This spring was the water supply for a former distillery, but there is no mention of this spring in the literature. The estimated base-flow for B. Riddle Spring is 0.1 ft^3/s and the delineated basin area is 2.8 mi^2. The basin delineation is based on one tracer test, discussed below.

Trace # 07-02: Fishers swallet to B. Riddle Spring. Field reconnaissance along the unnamed tributary and its forks revealed only one injection site, which is a series of swallets about 0.6 mile upstream of the spring. On March 7, 2007 two ounces of eosine were injected into the swallet farthest downstream in this zone. On March 14 B. Riddle Spring was extremely positive for eosine. The inferred groundwater flow path for this trace was 3,262 feet, with an inferred groundwater velocity of >466 ft/day. A second analysis on March 16 was negative for eosine, which indicates that all the dye had passed through the system in less than one week. The groundwater velocity is probably much faster than 466 ft/day, but dye receptors were not exchanged often enough to make a more accurate assessment. Please refer to Figure 32 for a map of the trace and groundwater basin for B. Riddle Spring.

Pisgah Station & RR Springs. These two small springs are located on either side of the railroad tracks at their intersection with Pisgah Pike just east of Versailles. Pisgah Station Spring issues from a bedding plane inside an old spring house on the south side of the railroad tracks. This spring was reportedly used by the railroad when Pisgah Station was active. RR Spring is an overflow spring about 100 feet due north of Pisgah Station Spring. RR Spring discharges from a small conduit in the tree line along the north side of the railroad tracks. Flow estimates for both springs are “trickle” because very little water was observed discharging from either. However, Pisgah Station Spring is perennial while RR Spring flows only during wet weather.

Trace # 06-08: Pisgah East swallet to Pisgah Station & RR Springs. Pisgah East swallet is fed by Pisgah East Spring, approximately 600 feet to the west. On June 21, 2006 one ounce of SRB was injected into Pisgah East swallet with a natural flow of approximately 0.05 ft^3/s. Both springs were positive for SRB on June 26, 2006. This trace had an inferred groundwater flow path of 1337 feet and an inferred groundwater velocity of greater than 223 ft/day. Figure 33 shows a map of this tracer test.

Traces Not Recovered. A total of five dye injections conducted at three different sites were not recovered at any of the spring or in-stream monitoring points. One of these was replicated with a successful dye recovery.

Trace # 06-09: This was the initial tracer injected at Three Chimneys Sink. For this trace two ounces of SRB were used and flushed with 200 gallons of hauled water. This trace was replicated (#06-14) with positive recovery at Waterford Spring.

Traces # 06-10 and 06-13: Both of these tracers were conducted at Winstar West Sinkhole on the Winstar Farm between Pisgah Pike and Big Sink Road, approximately 4 miles northeast of Versailles. Eosine was used for both attempts; two-and-a-half ounces on the first and eight ounces on the second, each flushed with 200 gallons of hauled water. Neither trace was recovered.

Traces # 06-12 and 06-15: Both of these tracers were conducted from Three Chimneys East Sink in an attempt to replicate and verify a trace to Elkdale Spring. This sinkhole is located on the east side of Big Sink Road, just north of Three Chimneys Sink. The first attempt was made with five ounces of uranine and flushed with 200 gallons of hauled water. The second attempt was made with one pound of uranine and flushed with 800 gallons of hauled water. Neither trace was ever recovered. Figure 34 is a map showing the injection locations of the non-recovered traces discussed above.

Misbehaved Karst and HUC Assessment. Karst groundwater basins are intimately linked to surface drainage. Surface run-off into swallets and sinkholes strongly influences groundwater quantity and quality in karst regions. Also, karst drainage basins may or may not conform to surface drainage basins. White and Schmidt (1966) used the term "misbehaved" karst to describe groundwater basins that do not conform to topographic divides, such as groundwater flow paths underneath ridge tops. Ray and others (2006) identified seven spring basins in the Little River Watershed of Trigg and Christian counties in western Kentucky with misbehaved karst drainage. Their criterion for misbehaved karst drainage is "*verified conduit flow passing beneath a delineated 14-digit or lower HUC* [Hydrologic Unit Code] *boundary*". Based on this criterion, they found that 48% of the mapped karst groundwater basins in the Little River watershed are misbehaved.

There are 21 mapped karst groundwater basins that intersect the South Elkhorn Creek Watershed, representing a total land area of 76.5 mi^2. Applying a similar criterion described above to mapped spring basins intersecting the South Elkhorn Creek watershed we find that 26.4 mi^2 (35%) are misbehaved karst. This represents 14% of the total surface drainage area of South Elkhorn Creek. Please note that 11- and 14-digit HUCs have been superseded by 10- and 12-digit units. Therefore, the criterion used to define misbehaved karst in this assessment is verified conduit flow passing beneath a delineated 12-digit or lower HUC. Conduit flow beneath HUC boundaries was verified through tracer tests either from previous investigations or those conducted for this study.

Because karst drainage has the capacity to pirate water from one watershed into another, careful attention must be paid when using topographic divides for watershed boundaries. Response to hazardous materials releases can be greatly hampered if surface and subsurface drainage are incongruous, potentially causing efforts to be focused in the wrong area. This type of deviation has similar implications for surface water assessments, such as the TMDL program. If spring flow derived from outside of a surface watershed is not identified then management plans and mitigation strategies may fail to address all potentially problematic areas. In some cases, this incongruity can cause HUC delineations to be invalid (Ray and others, 2006).

Ten out of the twenty-one mapped spring basins in South Elkhorn Creek watershed deviate from topographic hydrologic divides. These deviations range from 4 to 87% of individual karst basins. The most notable deviations between karst and topographic drainages in the South Elkhorn Creek watershed occur in the Roaring Spring and Cedar Cove Spring basins. Roaring Spring has a basin area of 22.7 mi^2 and verified conduit flow beneath a 12-digit HUC boundary. This produces a misbehaved spring basin area of 11.4 mi^2 (50%), which is the largest misbehaved karst area in the watershed. Cedar Cove Spring has a basin area of 5.4 mi^2 and verified conduit flow beneath a 10-digit HUC boundary. This yields a misbehaved spring basin of 4.7 mi^2 (87%), which is the largest percentage of misbehaved karst in a single spring basin in the study area. Table 6 lists these ten springs with the ratios of misbehaved karst basin to total karst basin areas along with the receiving watershed.

Five of these ten misbehaved spring basins ultimately discharge within the greater Elkhorn Creek Watershed. However, five of the misbehaved spring basins (Cedar Cove Spring, Garretts Spring, WSP2 Spring, Mathews Spring and Webber Spring) pirate water completely out of the Elkhorn Creek Watershed and into adjacent surface drainage. Thus, on a larger scale the total misbehaved karst area is considerably less, 12.4 mi^2 (16 %) of mapped karst groundwater basins.

The map in Figure 35 shows three categories of karst *behavior*: 1) behaved karst with spring basins that conform to surface drainage, 2) misbehaved karst with verified conduit flow beneath a 12-digit HUC boundary and 3) misbehaved karst with verified conduit flow beneath a 10-digit HUC boundary. Figure 35 also includes the generalized groundwater flow routes – determined through tracer tests – that verify conduit flow beneath the various HUC boundaries.

The updated 10-digit HUC used for this assessment actually introduced error not present in the 11-digit HUC relative to the deviation of karst drainage from the topographic watershed divide. Based on the 11-digit HUC there are 9.4 mi^2 of misbehaved karst drainage pirating water into or out of South Elkhorn Creek. Following the conversion to the 10-digit HUC, misbehaved karst drainage increases to 14.9 mi^2. This increase is due to the inclusion of portions of the Garretts Spring and Mathews Spring basins in the southern corner of the watershed. Tracer tests in both of these areas verify that they drain to adjacent watersheds and that the original 11-digit HUC assessment was less erroneous.

Spring Basin	Misbehaved Basin Area (mi^2)	Total Basin Area (mi^2)	Misbehaved Basin Ratio	Receiving Watershed
Cedar Cove	4.7	5.4	**0.87**	**Kentucky River**
Garretts	5.7	6.7	**0.85**	**Clear Creek**
Nance	1.25	2.0	**0.63**	North Elkhorn Creek
Roaring	11.4	22.7	**0.50**	South Elkhorn Creek
WSP2	0.43	1.0	**0.43**	**Glenns Creek**
Mathews	0.9	2.5	**0.37**	**Jessamine Creek**
Webber	0.63	2.0	**0.32**	**Clear Creek**
Silver	0.54	2.5	**0.22**	South Elkhorn Creek
Slacks	0.9	7.4	**0.12**	North Elkhorn Creek
Steeles	0.15	3.8	**0.04**	South Elkhorn Creek

Table 6. Ratio of misbehaved karst basin area to total mapped karst basin area. Note: Receiving watershed name in bold denotes groundwater discharge outside of the greater Elkhorn Creek Watershed.

CONCLUSIONS

This study serves as a more focused, follow-up groundwater investigation to assess potential NPS impacts in one part of the Kentucky River basin. In particular South Elkhorn Creek watershed was chosen due to surface water impacts and the direct influence of its karst groundwater drainage on surface water. Groundwater and surface water are conjunctive systems, no more directly so than in karst terrane. Karst areas can be especially susceptible to contamination due to high groundwater velocities and the potential lack of natural filtration for recharge. In karst areas, springs maintain base flow and therefore impart significant water quality characteristics on surface streams.

Groundwater quality sample results indicate definite NPS impacts to groundwater from *E. coli*, pesticides, total suspended solids (TSS), nitrate (as N), orthophosphate (as P) and total phosphorus in this watershed. Potential NPS impacts were noted for chloride. Aside from a few exceptions, there seems to be little or no evidence of a relationship between land-use types (agricultural vs. urban/residential) and overall groundwater quality in the study area. *E. coli* was present in all study-area springs, although concentrations were not significantly different based on land-use. Pesticides were detected at springs throughout the watershed, but were most frequently found at a single spring draining an urban area. Medain TSS values for each land-use type were equivalent, although higher median TSS values associated with storm water runoff were found in springs draining lower sections of South Elkhorn Creek, which are predominantly agricultural areas. The median nitrate (as N) value of springs draining agricultural areas was only slightly higher than those draining urban areas. Springs draining urban areas showed a higher median orthophosphate (as P) value than those draining agricultural areas. Median total phosphorus values were greater in springs draining agricultural areas than those draining urban areas. Chloride concentrations were higher in study area springs draining urban areas, but were found at all study area springs at varying levels below the SDWR. Both of the major land-use types in this watershed are responsible for NPS impacts identified. Additionally, there seems to be little association between groundwater quality and surface stream assessments in the study area.

For this study, twelve tracer tests were conclusive, which allowed for the delineation of two additional karst groundwater basins and identification of other previously unknown hydrologic connections. These data in combination with previous tracer data were used to assess USGS Hydrologic Unit Code (HUC) delineations for surface watersheds. Karst groundwater basin deviations from topographic watershed divides have serious implications for hydrologic modeling, TMDL development and emergency response.

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Appendix A. Financial and Administrative Closeout

Workplan Outputs

The [former] Groundwater Branch has committed to the following outputs:

- Identification of suitable groundwater monitoring sites in South Elkhorn Creek watershed
- Collection of samples from 22 sites with a minimum quarterly frequency for one year and delivering these samples to the laboratory for analysis for several parameters, including major inorganic ions, nutrients, pesticides, metals, volatile organic compounds and residues
- Data analysis, including data collected within this basin for other projects
- Production of a report summarizing all relevant groundwater data for this watershed
- Delivering hard-copies of the basin report to the River Basin Teams, local conservation districts, Natural Resource Conservation Service, Agricultural Water Quality Authority, Agricultural Extension offices and interested stakeholders
- Posting the report on the Division of Water's internet site

Budget Summary

- Total project budget is $146,000.00
- Budget has been expended in personnel costs
- The [former] Groundwater Branch has managed the project, including:
    - ✓ researching background data
    - ✓ conducting on-site inspections to identify sampling sites
    - ✓ collecting groundwater samples
    - ✓ transporting samples to the laboratory
    - ✓ interpreting sample results
    - ✓ preparing maps and reports
    - ✓ providing reports to interested parties

- Time code used for this project was:

Organization	57-129-01-09
Template	AP0587
Unit	DOW
Activity	MOAM and MODA

Project Budget:

The total project budget is $146,000. DOW personnel managed the project, researched background data, conducted on-site inspections and groundwater sampling, transported samples, interpreted sample results, prepared maps and report, and presented the summary information to stakeholders and other interested parties. The Environmental Services Branch (ESB) laboratory personnel conducted chemical analyses at the ESB lab. A time code was established to track personnel time spent on the project. Match for this grant provided by DOW and ESB personnel costs, included fringe and overhead.

Budget Summary:

Budget Categories	BMP Implementation	Project Management	Public Education	Monitoring	Technical Assistance	Other	Total
Personnel	$	$	$	$146,000	$	$	$146,000
Supplies							
Equipment							
Travel							
Contractual							
Operating Costs							
Other							
TOTAL	$	$	$	**$146,000**	**$**	**$**	**$146,000**

Detailed Budget

Budget Categories	Section 319(h)	Non-Federal Match	Total
Personnel	$87,600	$58,400	$146,000
Supplies	$	$	$
Equipment	$	$	$
Travel	$	$	$
Contractual	$	$	$
Operating Costs	$	$	$
Other	$	$	$
TOTAL	$**87,600**	**$58,400**	**$146,000**

Funds Expended

All funds for this project were expended using personnel dollars.

Equipment Summary

No equipment was purchased for this project.

Special Grant Conditions

No special grant conditions were placed on this project by the EPA.

Appendix B. Quality Assurance / Quality Control for Water Monitoring

QA/QC Plan for Assessment of Nonpoint Source Impacts on Groundwater Quality in South Elkhorn Creek Basin, Central Kentucky (BMU1, Round 2)

Prepared by

Peter T. Goodmann, Manager, [former] Groundwater Branch
James S. Webb (*ret.*), Supervisor, [former] Groundwater Branch
Robert J. Blair, Geologist-Registered, [former] Groundwater Branch

Kentucky Division of Water

1. Title Section

A. Project Name

Assessment of Nonpoint Source Impacts on Groundwater Quality in South Elkhorn Creek Basin, Central Kentucky (BMU1, Round 2)

B. QA/QC Plan Preparers

Peter T. Goodmann, Manager, [former] Groundwater Branch
James S. Webb (*ret*.), Supervisor, [former] Groundwater Branch
Robert J. Blair, Geologist-Registered, [former] Groundwater Branch
Kentucky Division of Water
200 Fair Oaks Lane
Frankfort, Kentucky 40601
(502) 564-3410

C. Date

January 31, 2004

D. Project Description

The project is part of the Kentucky River Strategic Watershed Monitoring Plan. The Kentucky Division of Water currently conducts quarterly nonpoint source groundwater monitoring at approximately 60 sites across the state. This project will expand that monitoring effort in the Kentucky River Basin by increasing the number of monitoring sites and focusing additional efforts of the existing monitoring network in this watershed. This project is intended to work in coordination with other members of the River Basin Team who are conducting surface water and biological sampling.

The goal of this project is to identify the impacts of nonpoint source pollution on the groundwater in the South Elkhorn Creek watershed, a sub-basin of the Kentucky River. The objective of this study is to identify aquifers that have been impacted by nonpoint source pollution. Problems in these areas will be identified in order that future nonpoint source resources may be properly focused regarding nonpoint source pollution prevention and pollution abatement.

2. Project Organization and Responsibility

A. Key Personnel

The [former] Technical Services Section of the Groundwater Branch will coordinate this project in cooperation with Data Management Section staff of the Groundwater Branch, Kentucky Division of Water.

The Groundwater Branch, Kentucky Division of Water, will scout and select suitable sampling locations. Groundwater Branch staff will perform sampling and sample delivery. The Kentucky Department for Environmental Protection's Division of Environmental Services laboratory will be responsible for sample analysis. All data generated will be delivered to the Kentucky Department for Environmental Protection's Consolidated Groundwater Database and will be forwarded to the Kentucky Geological Survey's Groundwater Data Repository.

Robert J. Blair, P.G., will be the Project Officer, QA Officer, and Field Sampling Officer. Address: 200 Fair Oaks Lane, Frankfort, KY 40601. Phone (502)-564-3410.

B. Laboratory

Environmental Services Branch
100 Sower Boulevard
Frankfort, Kentucky 40601
(502) 564-6120

C. Participating Agencies

The [former] Groundwater Branch, Division of Water currently conducts statewide ground water monitoring for the Ambient Groundwater Monitoring Program.

This project will cooperate with the Division of Water's Watershed Initiative, the Kentucky River Basin Team, and the Division of Water's Water Quality Branch.

3. Watershed Information

A. Stream Names

South Elkhorn Creek

B. Major River Basins

Kentucky River

USGS Hydrologic Unit Number (HUC)

Kentucky River Basin:	05100205
South Elkhorn Creek Basin:	051002050901 051002050902 051002050903 051002050904

C. Stream Order

This project encompasses South Elkhorn Creek, a sub-basin of the Kentucky River.

D. Counties in the Study Area

Jessamine, Fayette, Woodford, Scott and Franklin.

4. Monitoring Objectives

- Determine impacts of nonpoint source pollution on groundwater resources in South Elkhorn Creek watershed.
- Provide guidance for the nonpoint source program to focus future resources relating to nonpoint source pollution of groundwater.
- Support other programs, such as the Wellhead Protection program, the Groundwater Protection Plan program and the Agriculture Water Quality Authority.
- Provide additional data useful for the long-term management of the resource.

5. Study Area Description

South Elkhorn Creek basin is located in portions of Franklin, Scott, Woodford, Fayette and Jessamine counties. The headwaters originate in northern Jessamine and western Fayette counties and flow northwest to the confluence with North Elkhorn Creek in Franklin County. Agriculture represents 71% of the basin land use (56% pasture, 15% row crop). Forest makes up approximately 14% of the basin's land cover and Urban/Residential areas compose 14%. The majority of the urban and residential areas occur at the headwaters of several tributaries to South Elkhorn Creek (Town Branch, Wolf Run, Cave Creek and Brannon Run). The South Elkhorn Creek basin lies entirely within the Inner Bluegrass Physiographic Region of central Kentucky. This region is underlain by primarily flat-lying Ordovician limestone and shale.

The South Elkhorn Creek basin encompasses 179 square miles in portions of Franklin, Scott, Woodford, Fayette and Jessamine counties. The headwaters of South Elkhorn Creek rise in northern Jessamine and western Fayette counties then flow roughly northwest to the confluence with North Elkhorn Creek, forming the main stem of Elkhorn Creek. Approximately 300 miles of surface drainage flow through the basin. Due to well-developed karst drainage, numerous dry valleys occur in the basin. Major tributaries to South Elkhorn Creek include Town Branch, Brannon Run, Wolf Run and Cave Creek, all of which drain urban and residential areas. Elevations in South Elkhorn Creek basin range from 650 feet at the mouth to 1060 feet along the southeastern divide. The entire basin is located within the Inner Bluegrass Physiographic Region. Total population in the basin is approximately 250,000. This is mainly concentrated in Lexington, around the headwaters of Town Branch, Wolf Run and Cave Creek.

The principle karst aquifer in the South Elkhorn Creek basin is the Lexington Limestone Formation of the middle and upper Ordovician stratigraphic sequence. Complex inter-tonguing of individual members of the Lexington Limestone Formation exists throughout the basin. The Tanglewood Limestone is characterized as medium- to medium-dark-gray, fine- to coarse-grained, bioclastic, generally phosphatic and thinly bedded, with unit thickness ranging from 90 to 130 feet (Pomeroy, 1970). Pomeroy (1970) also notes minor shale units and some cross-bedded limestone within the Tanglewood. Near the bottom of the Tanglewood Limestone, where it inter-tongues with the Grier Limestone, Pomeroy identifies the Brannon Member. The Brannon Member is described as a thin limestone and shale sequence which is light- to medium gray, micrograined to very fine grained and thinly bedded with sparse fossils. Pomeroy (1970) describes the Grier Limestone Member as light- to dark-gray, micro- to coarse-grained (mostly medium-grained), thinly bedded, bioclastic and slightly phosphatic and typically on the order of 85 feet thick. Surface and subsurface karst features are common in both the Tanglewood and Grier Limestone Members. Although local variation does exist, these units generally have a gentle dip to the northwest.

Faulting within the basin is very minor and no regional fault systems intersect the watershed. The most notable faulting is associated with the meteor impact site northeast of Versailles which is believed to have occurred during the late Ordovician Period (~440 Ma) (Black, 1964). These faults are seen as nearly circular in plan view and are pronounced on the surface as a large ring of sinkholes. This seems to be the only area in the basin where regional groundwater flow is influenced by faulting.

Groundwater and surface water are conjunctive systems, no more directly so than in karst terrane. Subsurface streams are recharged via percolation through the soil and surface runoff into sinkholes and sinking streams. Conversely, groundwater discharges to surface streams at discrete springs. Springs often maintain base flow to surface streams and thus impart significant characteristics regarding water quantity and quality. South Elkhorn Creek basin is situated in the center of the Inner Bluegrass Karst Region of Kentucky. This area was rated as highly sensitive to groundwater contamination by Ray and others (1994).

6. Monitoring Program/Technical Design

A. Monitoring Approaches

Monitoring of approximately 20 sites will begin in April 2004. Specific sample sites will be selected after the Division of Water’s groundwater database has been reviewed for candidate sites and field inspection has confirmed that the candidate sites are suitable for monitoring. For all selected sites, either a Kentucky Water Well Record or a Kentucky Spring Inventory Form will be placed on record with the Division of Water. Duplicate samples will be collected for at least 10% of all samples in order to check reproducibility and provide QA/QC.

Field reconnaissance will be conducted prior to final site selection to assess the suitability and accessibility of each site. The appropriate Well Inspection or Spring Inventory records will be completed. Site locations will be plotted on 7.5-minute topographic maps, and identified by a site name and unique identification number (AKGWA number) for incorporation into the Department for Environmental Protection's Consolidated Groundwater Data Base and the Kentucky Geological Survey's Groundwater Data Repository.

B. Monitoring Station Location Strategy

All monitoring station locations will be in addition to other stations currently sampled in the basin. All monitoring sites will be karst groundwater basin springs or karst windows, fracture springs, contact springs or water wells.

C. Sample Frequency and Duration

Monitoring will begin in April 2004 and samples will be collected on at least a quarterly frequency through March 2005.

D. Sample Parameters, Containerization, Preservation, and Handling

Consistent with other monitoring efforts, samples will be collected at each spring or well and analyzed for some or all of the following: major inorganic ions; nutrients; total organic carbon; pesticides, including the most commonly used herbicides, insecticides, and fungicides; and dissolved and total metals. The analytical methods, containers, volumes collected, preservation, and sample transport will be consistent with the Division of Water's Standard Operating Procedures for Nonpoint Source Surface Water Quality Monitoring Projects, prepared by the Water Quality Branch (August, 1995) and current guidance from the Division of Environmental Services. Parameters to be measured, volume required for analysis, container type, preservative (if any), holding times (if any), and analytical methods are shown on the attached Chain-of-Custody Form.

Major inorganic ions are used to establish background groundwater chemistry and also used to measure impacts from nonpoint source pollutants such as abandoned mine lands and abandoned oil and gas production operations by measuring pH, alkalinity, chloride, sulfate, and fluoride. Nutrients and total organic carbon are used to measure impacts from agricultural operations (ammonia, nitrate, nitrite, TKN, and orthophosphate) and/or improper sewage disposal (nitrates, ammonia). Where sewage is suspected as a nonpoint source pollutant, unbleached cotton fabric swatches may be used to detect optical brighteners, the whitening agents used in laundry products and commonly found in sewage (Quinlan, 1987). Pesticides are measured to determine both rural agriculture and urban domestic- and commercial-use impacts on ground water. Metals are used to establish the rock-groundwater chemistry, establish local and regional backgrounds for metals, and determine nonpoint source impacts from abandoned coal mine operations.

All samples will be analyzed by the Environmental Services Branch laboratory according to the appropriate EPA method.

7. Chain-of-Custody Procedures

Sample containers will be labeled with the site name and well or spring identification number, sample collection date and time, analysis requested, preservation method, and collector's initials. Sampling personnel will complete a Chain-of-Custody Record, developed in conjunction with the DES laboratory, for each sample. The DES laboratory will be responsible for following approved laboratory QA/QC procedures, conducting analyses within the designated holding times, following EPA-approved analytical techniques, and reporting analytical results to the Groundwater Branch.

A sample Chain-of-Custody Form is attached.

8. Quality Assurance/Quality Control Procedures

A. Decontamination Protocols

All sampling supplies that come in contact with the sample will be new, disposable equipment, or will be decontaminated prior to and after each use, using the following protocols.

Sample Collection and Filtration Equipment

Whenever possible, sample collection is conducted using the sample container, except for dissolved metals, which are filtered on site. Sample collection equipment such as bailers and buckets will consist of Teflon. Pesticide samples will be collected using the sample container or a stainless steel bailer or bucket, in order to avoid the problem of pesticide adsorption to the sampling device (as is considered to occur with Teflon instruments). Any reusable equipment will be decontaminated by rinsing with a 10% hydrochloric acid (HCl) solution, triple rinsed with deionized water, and triple rinsed with water from the source to be sampled prior to collecting a sample. After sampling is complete, excess sample will be disposed of, and the equipment will again be rinsed with the 10% HCl solution and triple rinsed with deionized water.

New 0.45 micron filters will be used at each sampling site. Any tubing that contacts the sample will also be new. Any reusable filter apparatus will be decontaminated in the same manner as sample collection equipment. Additionally, any intermediary collection vessel will be triple rinsed with filtrate prior to use.

Field Meters

Field meter probes will be rinsed with deionized water prior to and after each use.

B. Equipment Calibration

Field meters will be calibrated in accordance with the manufacturer’s instructions. Records of cleaning and calibration are maintained with each field meter.

C. Sample Collection and Preservation/Contamination Prevention

Water samples will be fresh groundwater collected prior to any type of water treatment. Samples not requiring field filtration will be collected directly in the sampling container. Samples requiring field filtration will be collected directly into a new clean sampling container and will be transferred to the appropriate new clean sample container during the filtration process container. New disposable single use filters and tubing will be used in the filtration process. Pesticide samples will be collected using the sample container or a stainless steel bailer or bucket, wherever necessary.

Sample containers will be obtained from approved vendors, and will be new or laboratory-decontaminated in accordance with Division of Environmental Services accepted procedures. Sample containerization, preservation, and holding time requirements are outlined in the Division of Water's Standard Operating Procedures for Nonpoint Source Surface Water Quality Monitoring Projects, prepared by the Water Quality Branch (August, 1995) and current guidance from the Division of Environmental Services. Necessary preservatives will be added in the field; preservatives for dissolved constituents will be added after field filtration. Samples will be stored in coolers packed with ice for transport to the Division of Environmental Services laboratory.

Sample containers will be labeled with the site name and identification number, sample collection date and time, analysis requested, preservation method, and collector's initials. Sampling personnel will complete a Chain-of-Custody Record for each sample. The Division of Environmental Services laboratory will be responsible for following approved laboratory QA/QC procedures, conducting analyses within the designated holding times, following EPA-approved analytical techniques, and reporting analytical results to the Groundwater Branch.

Wells will be purged until conductivity readings stabilize prior to sampling, in order to ensure that groundwater, rather than water that has been standing in the well bore, is being sampled. Spring samples will be collected as close to the spring resurgence as possible. If inhospitable terrain prohibits spring access, a decontaminated Teflon bucket attached to a new polypropylene rope may be lowered to the spring to collect the sample. Samples for pesticide analysis will be collected using a stainless steel bucket.

Duplicates and Blanks

Duplicate samples will be collected for at least 10% of all samples in order to check reproducibility and provide QA/QC control. At least one duplicate sample will be submitted with each batch of samples, regardless of the number of samples in the batch. Blanks of deionized water will be submitted at least once per quarter. Blanks will be collected, filtered, and preserved in the same manner as a sample. According to Division of Environmental Services accepted procedures, duplicate analyses will be accepted if they are within 20 % rsd. If unacceptable results are found, samples will be re-analyzed and field records will be examined to determine the cause.

Field Measurements

Conductivity, temperature, and pH will be measured in the field at each site using portable automatic temperature compensating meters, and recorded in a field log book. Meters will be calibrated according to the manufacturer's specifications, using standard buffer solutions. Meter probes will be decontaminated according to decontamination protocols for field meters and stored according to the manufacturer's recommendations.

9. References

Black, D.F.B., 1964, Geology of the Versailles Quadrangle, United States Geological Survey, MAP GQ – 325.

Kentucky Division of Water, 1995, Standard operating procedures for nonpoint source surface water quality monitoring projects: Kentucky Natural Resources and Environmental Protection Cabinet, Frankfort, KY, 138 p.

McDowell, Robert C., Grabowski, Gilbert J, Moore, Samuel L., 1988, Geologic Map of Kentucky, Sesquicentennial Edition of the Kentucky Geological Survey, by U.S. Geological Survey, Daniel Peck, Director, and in cooperation with the Kentucky Geological Survey, Donald C. Haney, State Geologist and Director. Compiled by Martin C. Noger, Kentucky Geological Survey.

Pomeroy, J.S., 1970, Geologic Map of the Midway Quadrangle, United States Geological Survey, MAP GQ – 856.

Quinlan, J. F., ed., 1987, Qualitative water-tracing with dyes in karst terrains – Practical karst hydrogeology, with emphasis on groundwater monitoring, National Water Well Association 26 p.

Ray, Joseph, Webb, James, S., and O'dell, Phillip W., 1994, Groundwater Sensitivity Regions of Kentucky, Kentucky Department for Environmental Protection, Division of Water, Groundwater Branch, map.

CHAIN OF CUSTODY RECORD
ENERGY and ENVIRONMENT CABINET
DIVISION OF WATER - WATERSHED MANAGEMENT BRANCH - GROUNDWATER – WPC0603Z

Site Identification	Collection Date/Time	Field Measurements
? – Complaint/1x Sample Site Location: County: AKGWA #:	Date: ___________ Time: ___________	pH: _______ Conductivity: _________ μmhos Temp: ______ °C Spring flow: _____________

Sampler ID: ___________________________

Division for Environmental Services Samples			
Analysis Requested	**Container Size, Type**	**Preservation Method**	**Parameters**
	1000 ml Plastic Boston Round	Cool to 4°C	**Bulk Parameters** Chloride, Conductivity, Fluoride, Nitrate-N, Nitrite-N, pH, Sulfate, TSS, TDS, Ortho-P
	1000 ml Plastic Boston Round	H_2SO_4 Cool to 4°C	**Nutrients** NH_3 / TKN / TOC/Total Phosphorous
	1000 ml Plastic Boston Round	Filtered HNO_3 Cool to 4°C	**Dissolved Metals by ICP** Plus: Arsenic, Lead, Mercury, Selenium
	1000 ml Plastic Boston Round	HNO_3 Cool to 4°C	**Total Metals by ICP** plus Arsenic, Lead, Mercury, Selenium
	1000 ml Amber Glass	Cool to 4°C	**NP Pesticides** **Pesticides/PCBs** Methods 507/508
	1000 ml Amber Glass	5ml HCl Cool to 4°C	**Herbicides/Caffeine**
	250 ml HDPE Wide Mouth	Cool to 4°C NO HEAD SPACE	**Alkalinity**
	Three 40ml Amber Glass	50% HCl Cool to 4°C	**VOCs** (Trip Blank Required)
	125ml Amber Glass	Cool to 4º C	**Glyphosate**
	Two - 1000 ml Amber Glass	5ml HCl Cool to 4°C	**Duplicate** (only collect if requested)

Signatures:
Relinquished by: ______________________________________
Received by: ______________________________________
Date: ___________ Time: _________

Relinquished by: ______________________________________
Received by: ______________________________________
Date: ___________ Time: _________

Relinquished by: ______________________________________
Received by: ______________________________________
Date: ___________ Time: _________

Sample #: __________________ Report #: __________________
DISCARD SAMPLES UPON COMPLETION

Comments:

H_2SO_4 ________________ (Expiration Date)

HNO_3 ________________ (Expiration Date)

HCl (1:1) ______________(Expiration Date)

Appendix C. Conversion Factors

Conversion Factors

Multiply	by	To obtain
acre	43559.66	ft^2
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
gallon per minute (gpm)	0.06308	liter per second (L/s)
cubic feet per second (ft^3/s)	0.02832	cubic m per second (m^3/s)
$ft^3/s/mi^2$ (cfsm)	10.931	$L/s/km^2$ (lsk)
foot per mile (ft/mi)	0.1894	meter per km (m/km)
square mile (mi^2)	640.0	acres
mi^2	2.590	km^2
acre (ac)	0.4047	hectare (ha)
ounce (oz)	28.35	gram (g)
pound (lb)	0.454	kilogram (kg)
km	0.621	mi
$L/s/km^2$	0.0915	$ft^3/s/mi^2$
km^2	0.386	mi^2
meter	3.28	feet
m^3/s	35.31	ft^3/s
m/km	5.28	ft/mi
kg	2.20	lb
hectare	2.471	acre

APPENDIX D
Summary Tables of Statistical Analyses

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - BULK PARAMETERS						
Conductivity (µmho)						
	START DATE	**END DATE**	**MIN**	**MEDIAN**	**MAX**	**MODE**
OVERALL	**04/27/95**	**03/27/07**	**288**	**485**	**1175**	**413**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	288	426	638	413
URBAN/RESIDENTIAL	04/27/95	03/27/07	321	605	1175	444
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	288	401	525	346
LIVESTOCK	01/28/04	03/09/05	358	464	638	414
POND	01/28/04	03/27/07	431	611	878	-
UNUSED	04/27/95	03/27/07	308	497	1175	413
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	379	606	1175	444
HEADWATERS - SOUTH	01/28/04	05/25/05	321	378	496	346
LOWER	10/16/96	05/25/05	308	431	638	413
MIDDLE	01/28/04	03/06/07	288	444	608	392
Hardness (mg/L)						
	START DATE	**END DATE**	**MIN**	**MEDIAN**	**MAX**	**MODE**
OVERALL	**04/30/98**	**03/27/07**	**138.227**	**230.517**	**392.98**	**-**
BY LAND USE						
AGRICULTURAL	04/30/98	03/06/07	138.227	211.171	301.896	-
URBAN/RESIDENTIAL	05/20/98	03/27/07	151.15	253.3	392.98	-
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	138.227	194.991	288.37	-
LIVESTOCK	01/28/04	03/09/05	162.028	227.254	301.896	-
POND	01/28/04	03/27/07	219.992	254.5445	309.235	-
UNUSED	04/30/98	03/27/07	151.15	227.415	392.98	-
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	05/20/98	03/27/07	175.345	259.287	392.98	-
HEADWATERS - SOUTH	01/28/04	05/25/05	138.227	175.983	227.628	-
LOWER	04/30/98	05/25/05	163.564	213.525	285.501	-
MIDDLE	01/28/04	03/06/07	175.445	226.163	301.896	-
pH (pH units)						
	START DATE	**END DATE**	**MIN**	**MEDIAN**	**MAX**	**MODE**
OVERALL	**04/27/95**	**03/27/07**	**6.78**	**7.5**	**8.41**	**7.4**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	7.05	7.59	8.41	7.46
URBAN/RESIDENTIAL	04/27/95	03/27/07	6.78	7.4	8.07	7.4
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	7.05	7.59	8	7.56
LIVESTOCK	01/28/04	03/09/05	7.17	7.725	8.41	7.54
POND	01/28/04	03/27/07	7.06	7.45	8.07	7.44
UNUSED	04/27/95	03/27/07	6.78	7.44	8.24	7.4
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	6.78	7.36	8.07	7.4
HEADWATERS - SOUTH	01/28/04	05/25/05	7.16	7.56	8.41	7.56
LOWER	10/16/96	05/25/05	7.05	7.55	8.29	7.51
MIDDLE	01/28/04	03/06/07	7.05	7.66	8.34	7.66

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - INORGANICS

Chloride (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**2.51**	**20.3**	**189**	**10.2**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	2.51	9.67	40	10.2
URBAN/RESIDENTIAL	04/27/95	03/27/07	3.38	42.8	189	26.2
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	5.99	9.075	17.1	-
LIVESTOCK	01/28/04	03/09/05	3.19	9.705	40	6.87
POND	01/28/04	03/27/07	22.6	40.7	137	-
UNUSED	04/27/95	03/27/07	2.51	26.2	189	3.38
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	13.3	46	189	26.2
HEADWATERS - SOUTH	01/28/04	05/25/05	3.38	9.74	32.9	12.8
LOWER	10/16/96	05/25/05	2.51	9.71	40	4.12
MIDDLE	01/28/04	03/06/07	5.99	8.505	32.2	10.2

Fluoride (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.05**	**0.196**	**0.61**	**0.2**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.052	0.191	0.413	0.16
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.05	0.2	0.61	0.2
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.076	0.183	0.31	0.164
LIVESTOCK	01/28/04	03/09/05	0.087	0.2	0.291	0.207
POND	01/28/04	03/27/07	0.162	0.219	0.396	-
UNUSED	04/27/95	03/27/07	< 0.05	0.192	0.61	0.2
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.05	0.202	0.61	0.2
HEADWATERS - SOUTH	01/28/04	05/25/05	0.076	0.173	0.335	0.156
LOWER	10/16/96	05/25/05	0.052	0.196	0.413	0.16
MIDDLE	01/28/04	03/06/07	0.111	0.192	0.3	0.175

Sulfate (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**7.65**	**24**	**80.8**	**18.7**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	7.65	18.8	36.5	18.7
URBAN/RESIDENTIAL	04/27/95	03/27/07	11.1	42.05	80.8	25.8
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	11.3	20	36.5	11.8
LIVESTOCK	01/28/04	03/09/05	13.4	18.8	26.8	17.4
POND	01/28/04	03/27/07	25.8	36.65	51.8	-
UNUSED	04/27/95	03/27/07	7.65	26.8	80.8	18.3
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	21.5	43.5	80.8	25.8
HEADWATERS - SOUTH	01/28/04	05/25/05	11.1	17.3	36.5	11.8
LOWER	10/16/96	05/25/05	7.65	19.3	34.9	18.3
MIDDLE	01/28/04	03/06/07	13.4	18.25	26	16.3

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - METALS

Arsenic (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.000201**	**< 0.0005**	**< 0.05**	**< 0.0005**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.000201	< 0.0005	< 0.05	< 0.0005
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.000206	< 0.0005	< 0.05	< 0.0005
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.000201	< 0.0005	0.000681	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	< 0.0005	0.000679	< 0.0005
POND	01/28/04	03/27/07	0.000206	< 0.0005	0.00102	< 0.0005
UNUSED	04/27/95	03/27/07	0.000215	< 0.0005	< 0.05	< 0.0005
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.000206	< 0.0005	< 0.05	< 0.0005
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0005	< 0.0005	0.000649	< 0.0005
LOWER	10/16/96	05/25/05	< 0.0005	< 0.0005	< 0.05	< 0.0005
MIDDLE	01/28/04	03/06/07	0.000201	< 0.0005	0.000681	< 0.0005

Barium (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.00466**	**0.0232**	**0.0895**	**0.016**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.00466	0.016	0.0828	0.016
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.00956	0.03665	0.0895	0.034
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.0177	0.0259	0.0828	0.0177
LIVESTOCK	01/28/04	03/09/05	0.00466	0.008705	0.0345	0.00553
POND	01/28/04	03/27/07	0.0287	0.0402	0.0895	0.0348
UNUSED	04/27/95	03/27/07	0.00491	0.022	0.082	0.016
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.0146	0.0377	0.0895	0.034
HEADWATERS - SOUTH	01/28/04	05/25/05	0.00553	0.0177	0.0828	0.0106
LOWER	10/16/96	05/25/05	0.00466	0.016	0.036	0.016
MIDDLE	01/28/04	03/06/07	0.00536	0.01495	0.0561	0.00672

Iron (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.005**	**< 0.05**	**3.08**	**< 0.05**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 0.005	< 0.05	1.63	< 0.05
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.005	< 0.05	3.08	< 0.05
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.0158	< 0.05	0.788	< 0.05
LIVESTOCK	01/28/04	03/09/05	< 0.05	< 0.05	1.27	< 0.05
POND	01/28/04	03/27/07	0.0107	< 0.05	3.08	< 0.05
UNUSED	04/27/95	03/27/07	< 0.005	< 0.05	2.83	< 0.05
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.005	< 0.05	3.08	< 0.05
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.05	< 0.05	0.607	< 0.05
LOWER	10/16/96	05/25/05	< 0.005	< 0.05	1.63	< 0.05
MIDDLE	01/28/04	03/06/07	0.0158	< 0.05	1.27	< 0.05

Lead (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.0002**	**< 0.001**	**< 0.071**	**< 0.001**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.000238	< 0.001	< 0.071	< 0.001
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.0002	< 0.001	< 0.071	< 0.001
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.000238	< 0.001	0.00283	< 0.001
LIVESTOCK	01/28/04	03/09/05	< 0.001	< 0.001	< 0.001	< 0.001
POND	01/28/04	03/27/07	0.000255	< 0.001	< 0.001	< 0.001
UNUSED	04/27/95	03/27/07	0.0002	< 0.001	< 0.071	< 0.001
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.0002	< 0.001	0.071	< 0.001
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.001	< 0.001	0.0011	< 0.001
LOWER	10/16/96	05/25/05	< 0.001	< 0.001	0.071	< 0.001
MIDDLE	01/28/04	03/06/07	0.000238	< 0.001	0.00283	< 0.001

Manganese (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.0005**	**0.00762**	**1.01**	**< 0.003**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 0.0005	0.00597	0.4	< 0.003
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.0005	0.0177	1.01	< 0.003
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.0005	0.00266	0.326	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	0.004835	0.143	0.00238
POND	01/28/04	03/27/07	< 0.0005	0.003225	0.763	< 0.0005

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - NUTRIENTS

Ammonia-N (NH_3-N) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.02**	**< 0.05**	**0.43**	**< 0.05**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 0.02	< 0.05	0.0697	< 0.05
URBAN/RESIDENTIAL	05/07/96	03/27/07	< 0.02	< 0.05	0.43	< 0.05
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.025	< 0.05	< 0.05	< 0.05
LIVESTOCK	01/28/04	03/09/05	< 0.025	< 0.05	< 0.05	< 0.05
POND	01/28/04	03/27/07	< 0.025	< 0.05	< 0.05	< 0.05
UNUSED	05/07/96	03/27/07	< 0.02	< 0.05	0.43	< 0.05
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.02	< 0.05	0.43	< 0.05
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.025	< 0.05	0.0697	< 0.05
LOWER	10/16/96	05/25/05	< 0.02	< 0.025	< 0.05	< 0.05
MIDDLE	01/28/04	03/06/07	< 0.025	< 0.05	< 0.05	< 0.05

Nitrate-N (NO_3-N) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.793**	**4.015**	**28.2**	**3.14**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.793	5.34	28.2	3.1
URBAN/RESIDENTIAL	04/27/95	03/27/07	1.29	3.34	6.12	4.29
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	4.1	5.315	7.21	-
LIVESTOCK	01/28/04	03/09/05	2.52	7.2	13.3	3.86
POND	01/28/04	03/27/07	1.79	3.385	4.48	-
UNUSED	04/27/95	03/27/07	0.793	3.595	28.2	3.14
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	1.29	3.395	6.12	4.29
HEADWATERS - SOUTH	01/28/04	05/25/05	2.31	6.34	13.3	-
LOWER	10/16/96	05/25/05	0.793	5.34	28.2	3.1
MIDDLE	01/28/04	03/06/07	2.52	5.08	11.2	3.86

Nitrite-N (NO_2-N) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.001**	**0.021**	**0.038**	**< 0.025**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.002	< 0.02	< 0.025	< 0.02
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.001	< 0.025	0.038	< 0.025
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.02	< 0.025	< 0.025	< 0.025
LIVESTOCK	01/28/04	03/09/05	< 0.02	< 0.02	< 0.025	< 0.02
POND	01/28/04	03/27/07	< 0.02	< 0.025	< 0.025	< 0.025
UNUSED	04/27/95	03/27/07	< 0.001	< 0.02	0.038	< 0.025
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.001	< 0.025	0.032	< 0.025
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.02	< 0.02	0.038	< 0.02
LOWER	10/16/96	05/25/05	0.002	< 0.02	< 0.025	< 0.02
MIDDLE	01/28/04	03/06/07	< 0.02	< 0.025	< 0.025	< 0.025

Orthophosphate-P (PO_4-P) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.044**	**0.231**	**0.5**	**< 0.06**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 0.05	0.196	0.5	0.115
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.044	0.257	0.479	< 0.06
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.05	0.174	0.5	< 0.05
LIVESTOCK	01/28/04	03/09/05	< 0.06	0.206	0.486	< 0.06
POND	01/28/04	03/27/07	0.044	0.18	0.27	-
UNUSED	04/27/95	03/27/07	< 0.05	0.2545	0.479	< 0.06
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.044	0.259	0.479	< 0.06
HEADWATERS - SOUTH	01/28/04	05/25/05	0.061	0.221	0.5	0.136
LOWER	10/16/96	05/25/05	< 0.06	0.195	0.353	0.113
MIDDLE	01/28/04	03/06/07	< 0.05	0.163	0.389	< 0.05

Total Phosphorus (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**05/13/97**	**03/27/07**	**0.0958**	**0.32**	**5.45**	**0.32**
BY LAND USE						
AGRICULTURAL	05/13/97	03/06/07	0.0958	0.335	5.45	0.276
URBAN/RESIDENTIAL	05/13/97	03/27/07	0.202	0.31	0.581	0.3
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	0.16	0.284	0.971	-
LIVESTOCK	01/28/04	03/09/05	0.0958	0.3715	1.03	0.425

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - PATHOGENS

E. coli (#100mL)						
	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**03/16/04**	**10/10/06**	**< 1**	**170**	**> 2420**	**> 2400**
BY LAND USE						
AGRICULTURAL	03/16/04	10/10/06	1	160	>2400	> 2400
URBAN/RESIDENTIAL	03/16/04	10/10/06	17	185	> 2420	> 2400
BY SPRING USE						
DOMESTIC	03/16/04	10/10/06	< 1	37.5	820	96
LIVESTOCK	03/16/04	07/14/04	1	2000	> 2400	> 2400
POND	03/16/04	10/10/06	34	126	> 2400	44
UNUSED	03/16/04	10/10/06	< 1	158.5	> 2420	> 2400
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	03/16/04	10/10/06	17	249	> 2420	> 2400
HEADWATERS - SOUTH	03/16/04	07/14/04	< 1	135	> 2400	> 2400
LOWER	03/16/04	07/14/04	< 1	190	> 2400	< 1
MIDDLE	03/16/04	10/10/06	1	122	> 2400	> 2400

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - PESTICIDES

Alachlor (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.00002**	**< 0.0000421**	**< 0.00006**	**< 0.00004**
BY LAND USE						
AGRICULTURAL	03/25/97	03/06/07	< 0.00004	< 0.0000421	< 0.00006	< 0.00004
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.00002	< 0.0000417	< 0.00006	< 0.00004
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.00004	< 0.00004165	< 0.00005	< 0.0000408
LIVESTOCK	01/28/04	03/09/05	< 0.00004	< 0.0000421	< 0.0000533	< 0.0000417
POND	01/28/04	03/27/07	< 0.00004	< 0.0000419	< 0.0000444	< 0.0000426
UNUSED	04/27/95	03/27/07	< 0.00002	< 0.0000421	< 0.00006	< 0.00004
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.00002	< 0.0000417	< 0.00006	< 0.00004
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0000404	< 0.0000421	< 0.0000533	< 0.00004
LOWER	03/25/97	05/25/05	< 0.00004	< 0.000043	< 0.00006	< 0.00004
MIDDLE	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.0000533	< 0.00004

Atrazine (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.00002**	**< 0.0000426**	**0.000375**	**< 0.00004**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.00002	< 0.0000426	0.000375	< 0.0000417
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.0000265	< 0.0000421	0.0003	< 0.00004
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.00002	< 0.00004165	0.000375	< 0.0000408
LIVESTOCK	01/28/04	03/09/05	< 0.00004	< 0.000044	0.000225	< 0.0000417
POND	01/28/04	03/27/07	< 0.00004	< 0.0000419	< 0.0000444	< 0.0000426
UNUSED	04/27/95	03/27/07	0.00002	< 0.0000426	0.000372	< 0.00004
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	0.0000265	< 0.0000421	0.0003	< 0.00004
HEADWATERS - SOUTH	01/28/04	05/25/05	0.000032	< 0.0000435	0.000375	< 0.0000417
LOWER	10/16/96	05/25/05	0.00002	< 0.000044	0.000372	< 0.0000417
MIDDLE	01/28/04	03/06/07	< 0.00004	< 0.0000417	0.000119	< 0.0000408

Cyanazine (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 0.00004**	**< 0.0000421**	**< 0.0001**	**< 0.00004**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 0.00004	< 0.0000421	< 0.0001	< 0.00004
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.00004	< 0.0000421	< 0.0001	< 0.00004
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.0005	< 0.0000408
LIVESTOCK	01/28/04	03/09/05	< 0.00004	< 0.0000421	< 0.0000533	< 0.0000417
POND	01/28/04	03/27/07	< 0.00004	< 0.0000419	< 0.0000444	< 0.0000426
UNUSED	04/27/95	03/27/07	< 0.00004	< 0.0000421	< 0.0001	< 0.00004
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.00004	< 0.0000421	< 0.0001	< 0.00004
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0000404	< 0.0000421	< 0.0000533	< 0.0000417
LOWER	10/16/96	05/25/05	< 0.00004	< 0.0000426	< 0.0001	< 0.00004
MIDDLE	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.0000533	< 0.0000426

Metolachlor (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.0000274**	**< 0.0000421**	**< 0.0002**	**< 0.00004**
BY LAND USE						
AGRICULTURAL	03/25/97	03/06/07	0.0000274	< 0.0000421	< 0.0000533	< 0.00004
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 0.00004	< 0.0000422	< 0.0002	< 0.00004
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.00005	< 0.0000408
LIVESTOCK	01/28/04	03/09/05	< 0.00004	< 0.0000421	< 0.0000533	< 0.0000417
POND	01/28/04	03/27/07	< 0.00004	< 0.0000419	< 0.0000444	< 0.0000426
UNUSED	04/27/95	03/27/07	0.0000274	< 0.0000422	< 0.0002	< 0.00004
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 0.00004	< 0.0000421	< 0.0002	< 0.00004
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0000404	< 0.0000421	< 0.0000533	< 0.0000417
LOWER	03/25/97	05/25/05	0.0000274	< 0.0000421	< 0.00005	< 0.00004
MIDDLE	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.0000533	< 0.00004

Simazine (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**0.0000247**	**< 0.0000421**	**< 0.0003**	**< 0.00004**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	0.000029	< 0.0000421	< 0.0003	< 0.00004
URBAN/RESIDENTIAL	04/27/95	03/27/07	0.0000247	< 0.0000421	< 0.0003	< 0.00004
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.00004	< 0.0000417	< 0.00005	< 0.0000408
LIVESTOCK	01/28/04	03/09/05	< 0.00004	< 0.0000426	0.000119	< 0.00004
POND	01/28/04	03/27/07	0.0000247	< 0.0000417	< 0.0000444	< 0.0000426

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - RESIDUES

TDS (Total Dissolved Solids) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 5**	**286**	**872**	**278**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 5	256	438	278
URBAN/RESIDENTIAL	04/27/95	03/27/07	102	348	872	200
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 5	238	314	210
LIVESTOCK	01/28/04	03/09/05	180	278	402	198
POND	01/28/04	03/27/07	102	356	498	296
UNUSED	04/27/95	03/27/07	130	289	872	212
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	102	353	872	286
HEADWATERS - SOUTH	01/28/04	05/25/05	164	214	280	278
LOWER	10/16/96	05/25/05	170	256	438	212
MIDDLE	01/28/04	03/06/07	< 5	270	366	222

TSS (Total Suspended Solids) (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**04/27/95**	**03/27/07**	**< 1**	**2.5**	**102**	**< 1.5**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	< 1	2.5	102	< 1.5
URBAN/RESIDENTIAL	04/27/95	03/27/07	< 1	2.5	47	< 1.5
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 1	1.5	102	< 1.5
LIVESTOCK	01/28/04	03/09/05	< 1	2.5	51.5	< 1.5
POND	01/28/04	03/27/07	< 1	< 1.5	4.5	< 1.5
UNUSED	04/27/95	03/27/07	< 1	< 3	72	< 3
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	04/27/95	03/27/07	< 1	2	47	< 1.5
HEADWATERS - SOUTH	01/28/04	05/25/05	< 1	3	45	< 1.5
LOWER	10/16/96	05/25/05	< 1	3	72	< 1
MIDDLE	01/28/04	03/06/07	< 1	1.5	102	< 1.5

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - VOCs

Benzene (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**10/16/96**	**03/27/07**	**< 0.0005**	**< 0.0005**	**0.00147**	**< 0.0005**
BY LAND USE						
AGRICULTURAL	02/03/99	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
URBAN/RESIDENTIAL	10/16/96	03/27/07	< 0.0005	< 0.0005	0.00147	< 0.0005
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
POND	01/28/04	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
UNUSED	10/16/96	03/27/07	< 0.0005	< 0.0005	0.00147	< 0.0005
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	10/16/96	03/27/07	< 0.0005	< 0.0005	0.00147	< 0.0005
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LOWER	02/03/99	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
MIDDLE	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Toluene (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**10/16/96**	**03/27/07**	**0.00039**	**< 0.0005**	**0.00336**	**< 0.0005**
BY LAND USE						
AGRICULTURAL	02/03/99	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
URBAN/RESIDENTIAL	10/16/96	03/27/07	0.00039	< 0.0005	0.00336	< 0.0005
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
POND	01/28/04	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
UNUSED	10/16/96	03/27/07	0.00039	< 0.0005	0.00336	< 0.0005
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	10/16/96	03/27/07	0.00039	< 0.0005	0.00336	< 0.0005
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LOWER	02/03/99	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
MIDDLE	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Ethylbenzene (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**10/16/96**	**03/27/07**	**< 0.0005**	**< 0.0005**	**< 0.0005**	**< 0.0005**
BY LAND USE						
AGRICULTURAL	02/03/99	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
URBAN/RESIDENTIAL	10/16/96	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
POND	01/28/04	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
UNUSED	10/16/96	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	10/16/96	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LOWER	02/03/99	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
MIDDLE	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Total Xylenes (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**11/11/98**	**03/27/07**	**< 0.0005**	**< 0.0005**	**0.00672**	**< 0.0005**
BY LAND USE						
AGRICULTURAL	02/03/99	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
URBAN/RESIDENTIAL	11/11/98	03/27/07	< 0.0005	< 0.0005	0.00672	< 0.0005
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LIVESTOCK	01/28/04	03/09/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
POND	01/28/04	03/27/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005
UNUSED	11/11/98	03/27/07	< 0.0005	< 0.0005	0.00672	< 0.0005
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	11/11/98	03/27/07	< 0.0005	< 0.0005	0.00672	< 0.0005
HEADWATERS - SOUTH	01/28/04	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
LOWER	02/03/99	05/25/05	< 0.0005	< 0.0005	< 0.0005	< 0.0005
MIDDLE	01/28/04	03/06/07	< 0.0005	< 0.0005	< 0.0005	< 0.0005

MTBE (mg/L)

	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**02/03/99**	**03/27/07**	**0.000433**	**< 0.001**	**0.0501**	**< 0.001**
BY LAND USE						
AGRICULTURAL	02/03/99	03/06/07	< 0.001	< 0.001	< 0.02	< 0.001
URBAN/RESIDENTIAL	02/03/99	03/27/07	0.000433	< 0.001	0.0501	< 0.001
BY SPRING USE						
DOMESTIC	01/28/04	03/06/07	< 0.001	< 0.001	< 0.001	< 0.001
LIVESTOCK	01/28/04	03/09/05	< 0.001	< 0.001	< 0.001	< 0.001
POND	01/28/04	03/27/07	< 0.001	< 0.001	< 0.001	< 0.001

BMU1 South Elkhorn: DESCRIPTIVE STATISTICS - FIELD PARAMETERS

Field Conductivity (μmho)						
	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**07/26/95**	**03/27/07**	**290**	**513.5**	**1039**	**385**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	290	422	632	388
URBAN/RESIDENTIAL	07/26/95	10/28/08	353	601	1039	479
BY SPRING USE						
DOMESTIC	01/26/05	03/06/07	343	455	579	-
LIVESTOCK	01/05/05	03/09/05	360	413.5	503	-
POND	01/05/05	03/27/07	479	601	764	-
UNUSED	07/26/95	03/27/07	290	530	1039	385
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	07/26/95	03/27/07	445	606	1039	479
HEADWATERS - SOUTH	01/05/05	05/25/05	343	362	428	385
LOWER	10/16/96	05/25/05	290	388	632	388
MIDDLE	01/05/05	03/06/07	380	436	579	-

Field pH (pH units)						
	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**07/26/95**	**03/27/07**	**5.7**	**6.85**	**9.39**	**6.76**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	6.47	7.02	8.01	6.87
URBAN/RESIDENTIAL	07/26/95	10/28/08	5.7	6.8	9.39	6.76
BY SPRING USE						
DOMESTIC	01/26/05	03/06/07	6.47	6.84	7.12	-
LIVESTOCK	01/05/05	03/09/05	6.77	7.115	8.01	-
POND	01/05/05	03/27/07	6.46	6.8	6.97	6.76
UNUSED	07/26/95	03/27/07	5.7	6.86	9.39	6.76
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	07/26/95	03/27/07	5.7	6.785	9.39	6.76
HEADWATERS - SOUTH	01/05/05	05/25/05	6.77	7.02	7.81	-
LOWER	10/16/96	05/25/05	6.91	7.17	7.78	-
MIDDLE	01/05/05	03/06/07	6.47	6.87	8.01	7.05

Field Temperature (C)						
	START DATE	END DATE	MIN	MEDIAN	MAX	MODE
OVERALL	**07/26/95**	**03/27/07**	**9.2**	**14.45**	**19.8**	**14**
BY LAND USE						
AGRICULTURAL	10/16/96	03/06/07	9.2	12.6	18	12.6
URBAN/RESIDENTIAL	07/26/95	10/28/08	11.6	15.15	19.8	14
BY SPRING USE						
DOMESTIC	01/26/05	03/06/07	10.9	13.05	15.4	11.9
LIVESTOCK	01/05/05	03/09/05	9.2	12.45	13.6	12.6
POND	01/05/05	03/27/07	13.6	14.7	18.9	14
UNUSED	07/26/95	03/27/07	10.8	15	19.8	13
BY WATERSHED DESIGNATION						
HEADWATERS - NORTH	07/26/95	03/27/07	12.08	15.2	19.8	14
HEADWATERS - SOUTH	01/05/05	05/25/05	11.1	12.7	14.3	-
LOWER	10/16/96	05/25/05	10.8	12.5	18	-
MIDDLE	01/05/05	03/06/07	9.2	12.6	15.4	12.4

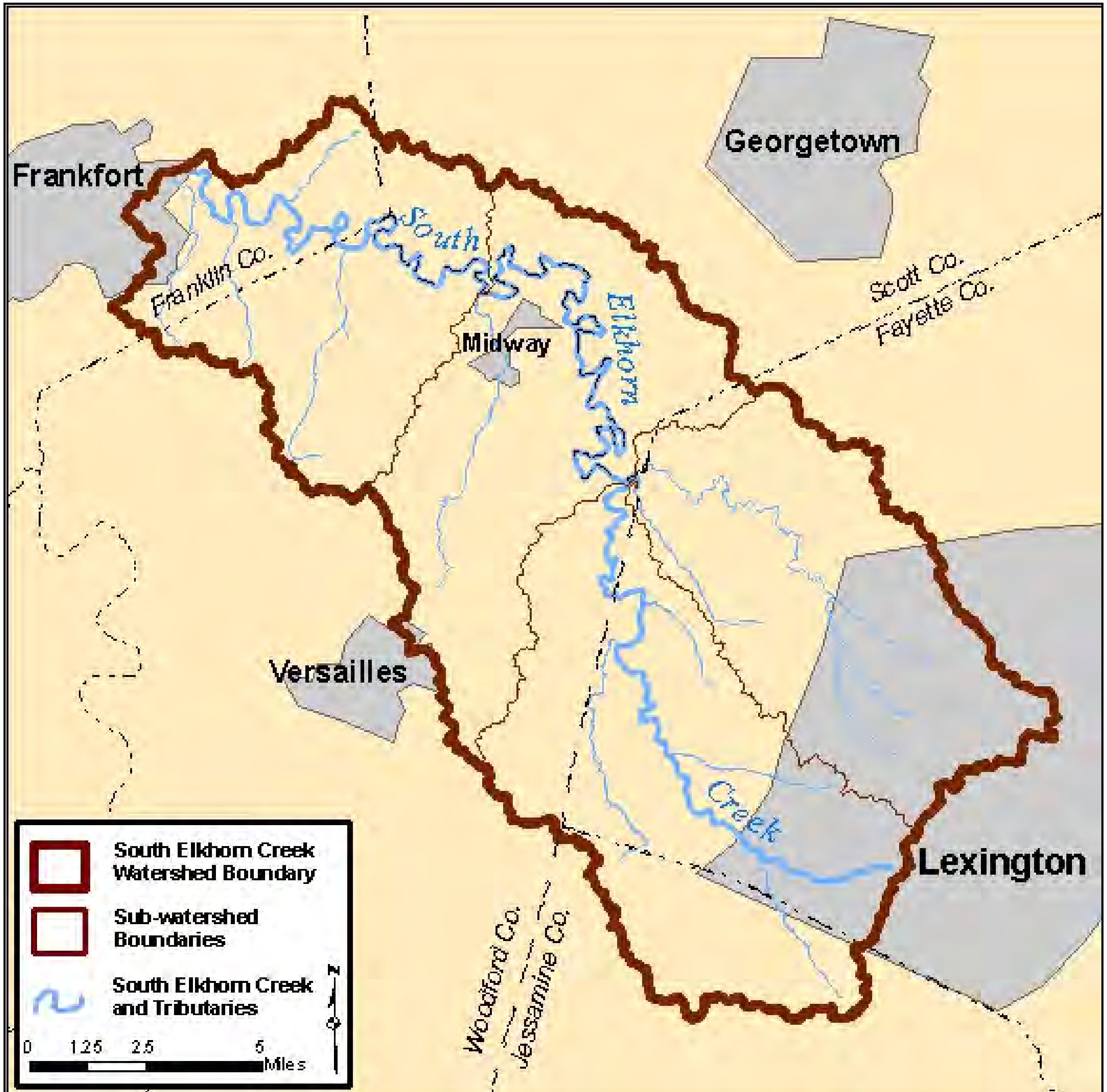


Figure 1. Study Area: South Elkhorn Creek and Watershed Boundaries

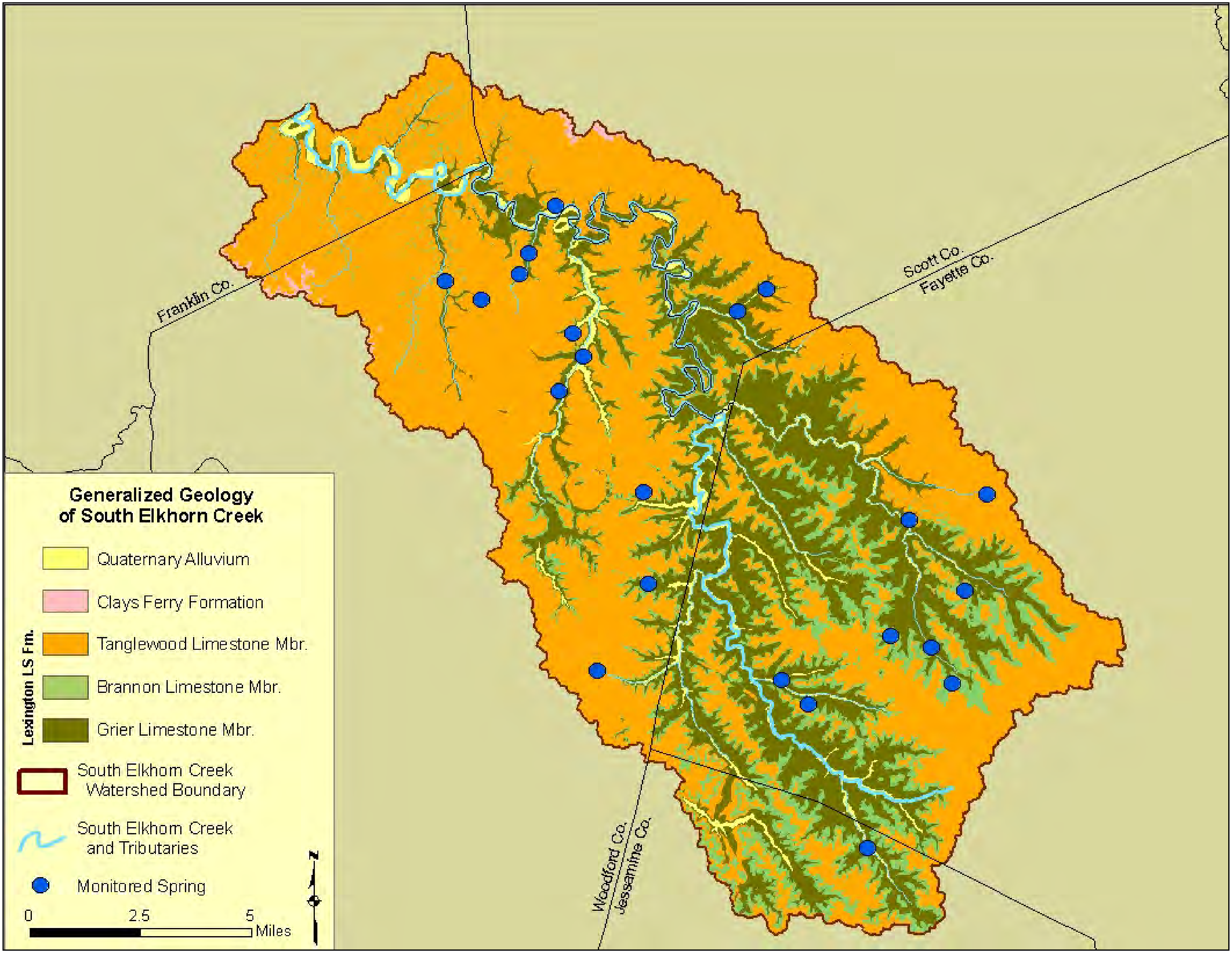


Figure 4. Geology of the South Elkhorn Creek Basin

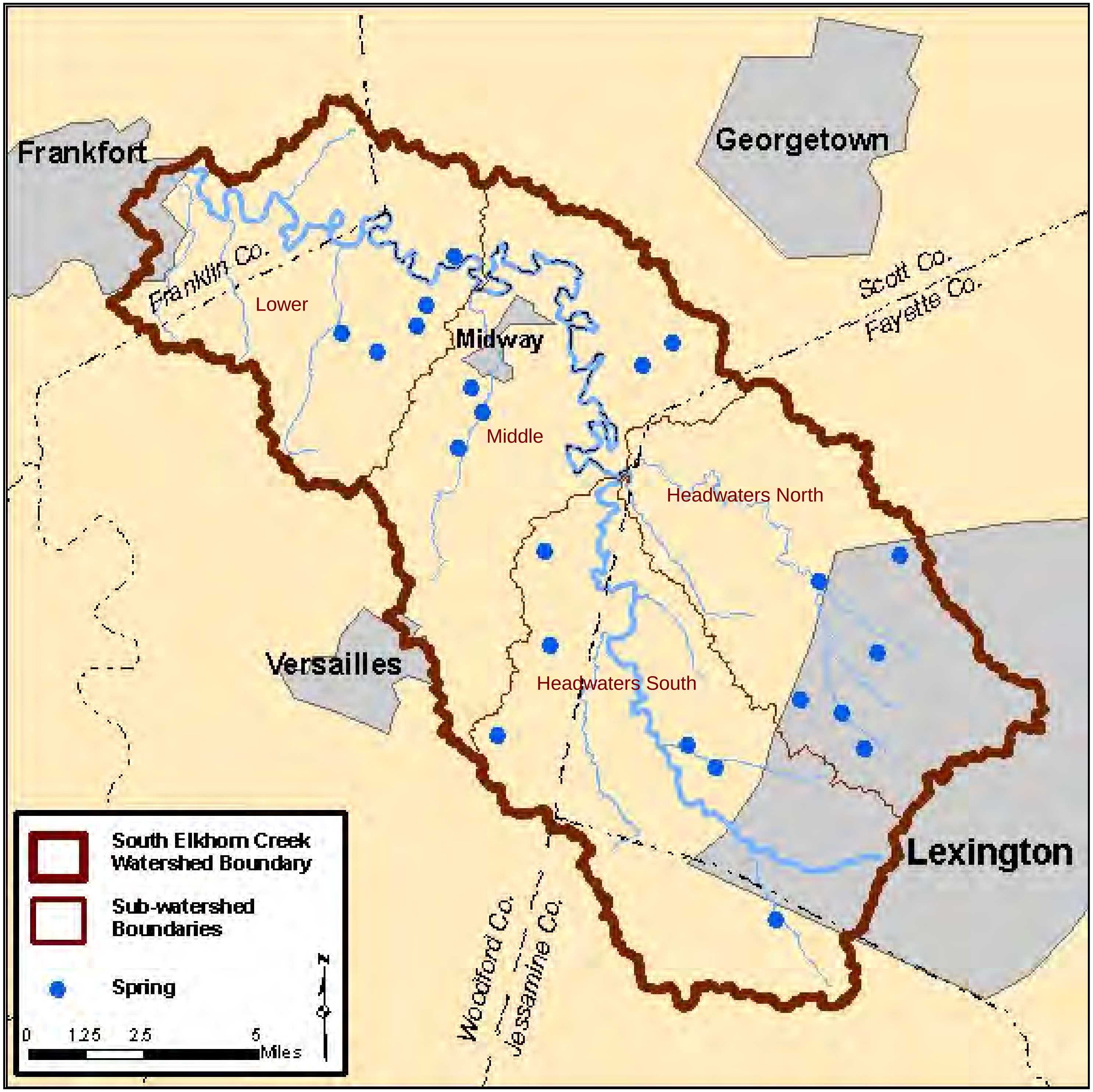


Figure 5. South Elkhorn Creek Watershed and sub-watershed boundaries with locations of springs monitored for water quality.

Figure 8: Activated charcoal packet dye receptors attached by trot-line clip to "Quinlan Gumdrop" or brick fitted with #10 copper wire. Devices secured to retrieval point with nylon cord.

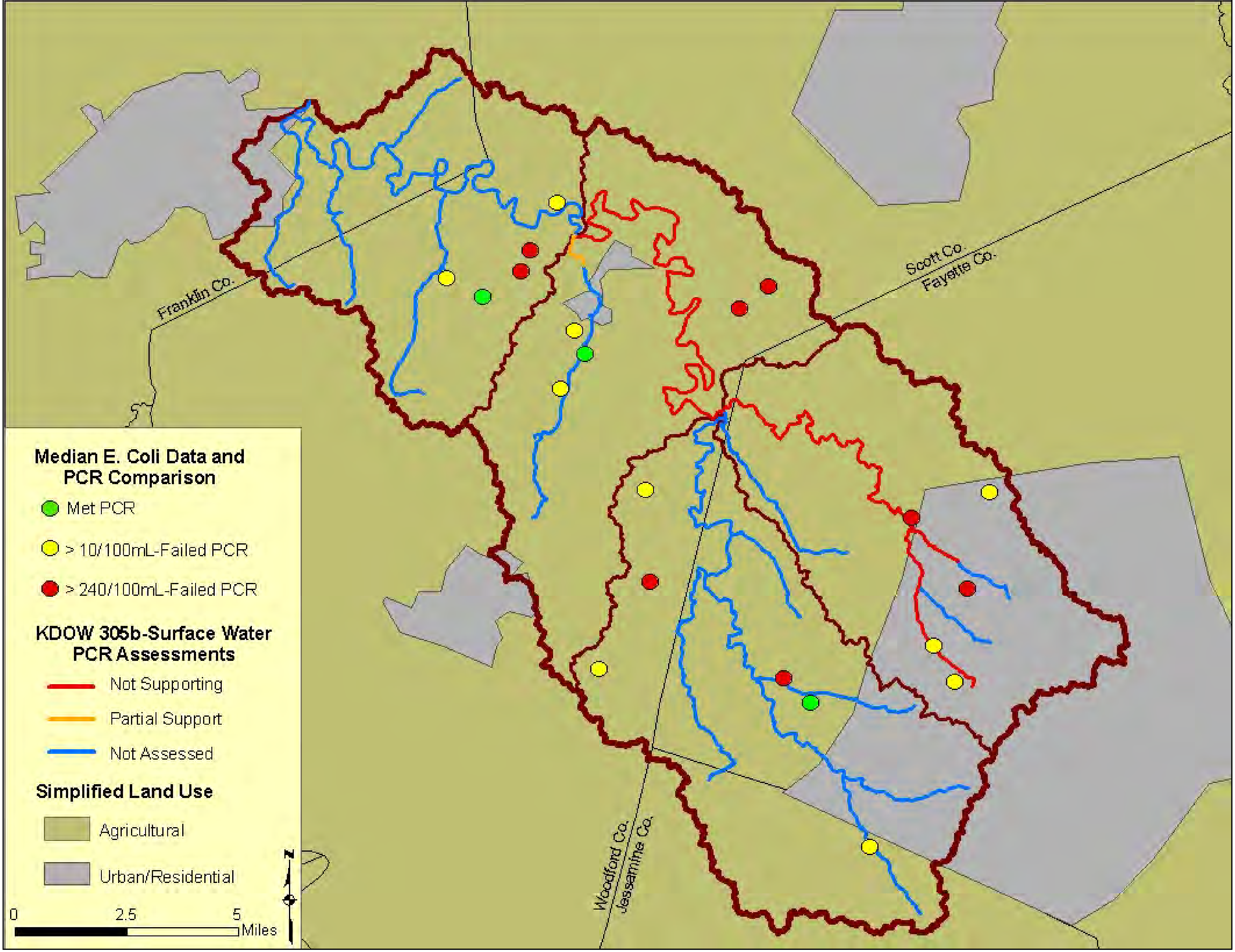
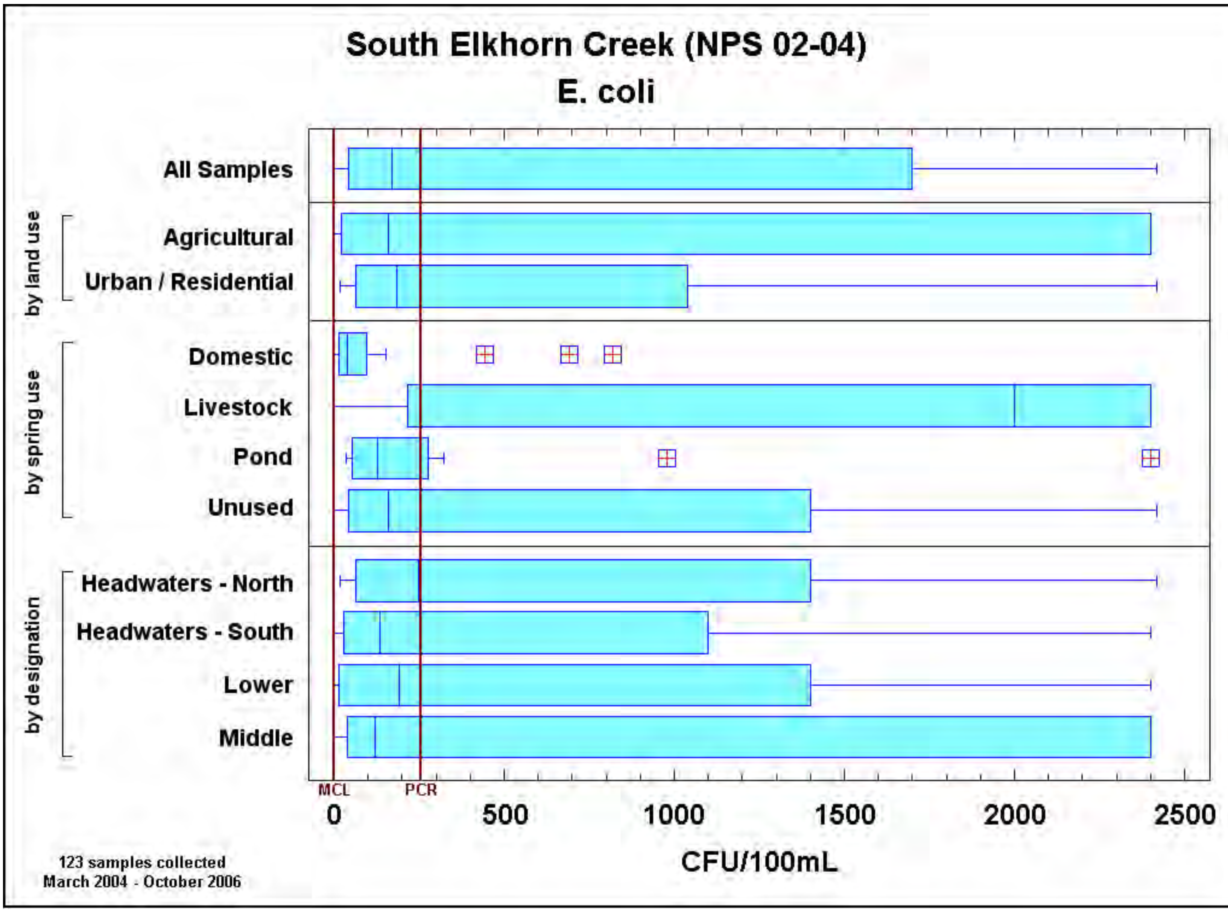


Figure 10. Median E. Coli data for study area springs compared to Primary Contact Recreation (PCR) standard



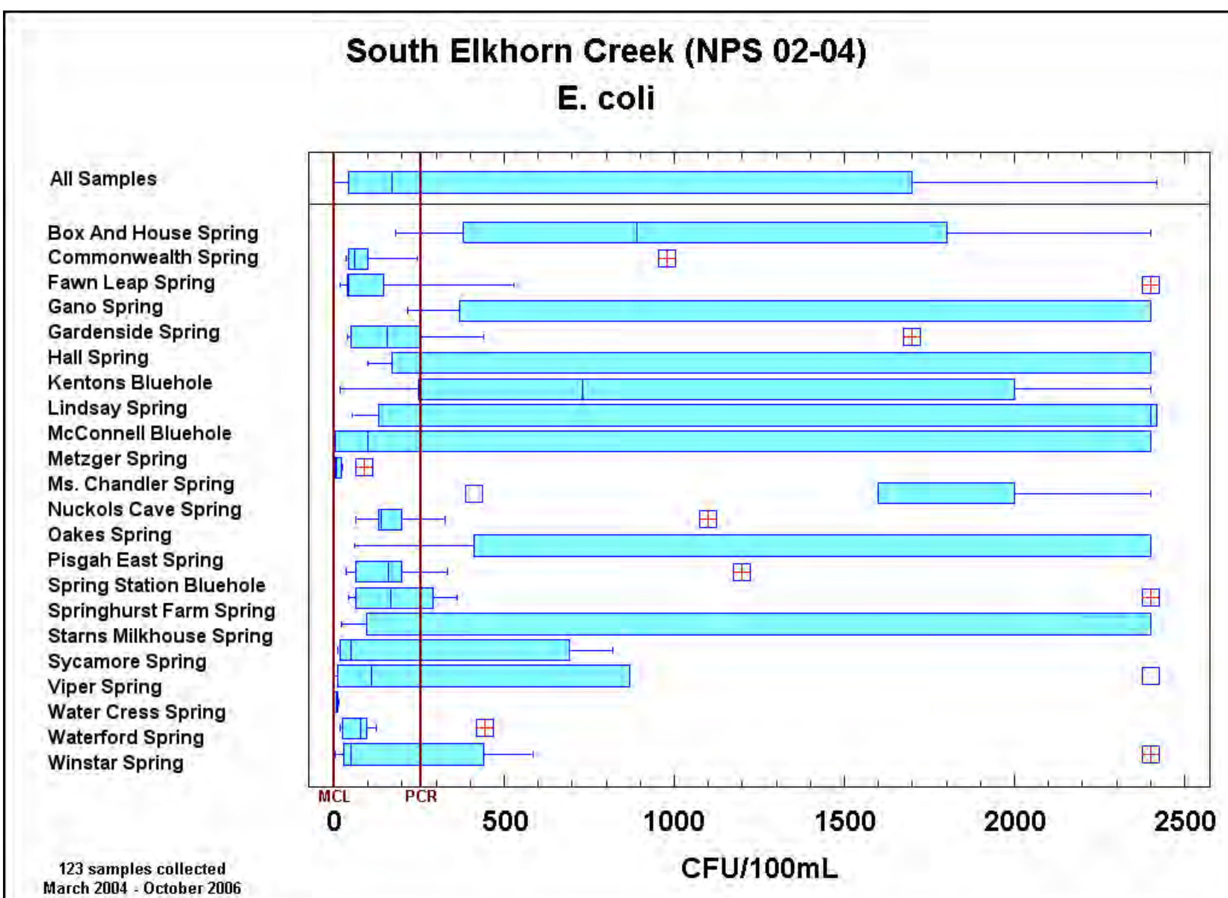


Figure 11. E. Coli Boxplots for monitored springs in study area

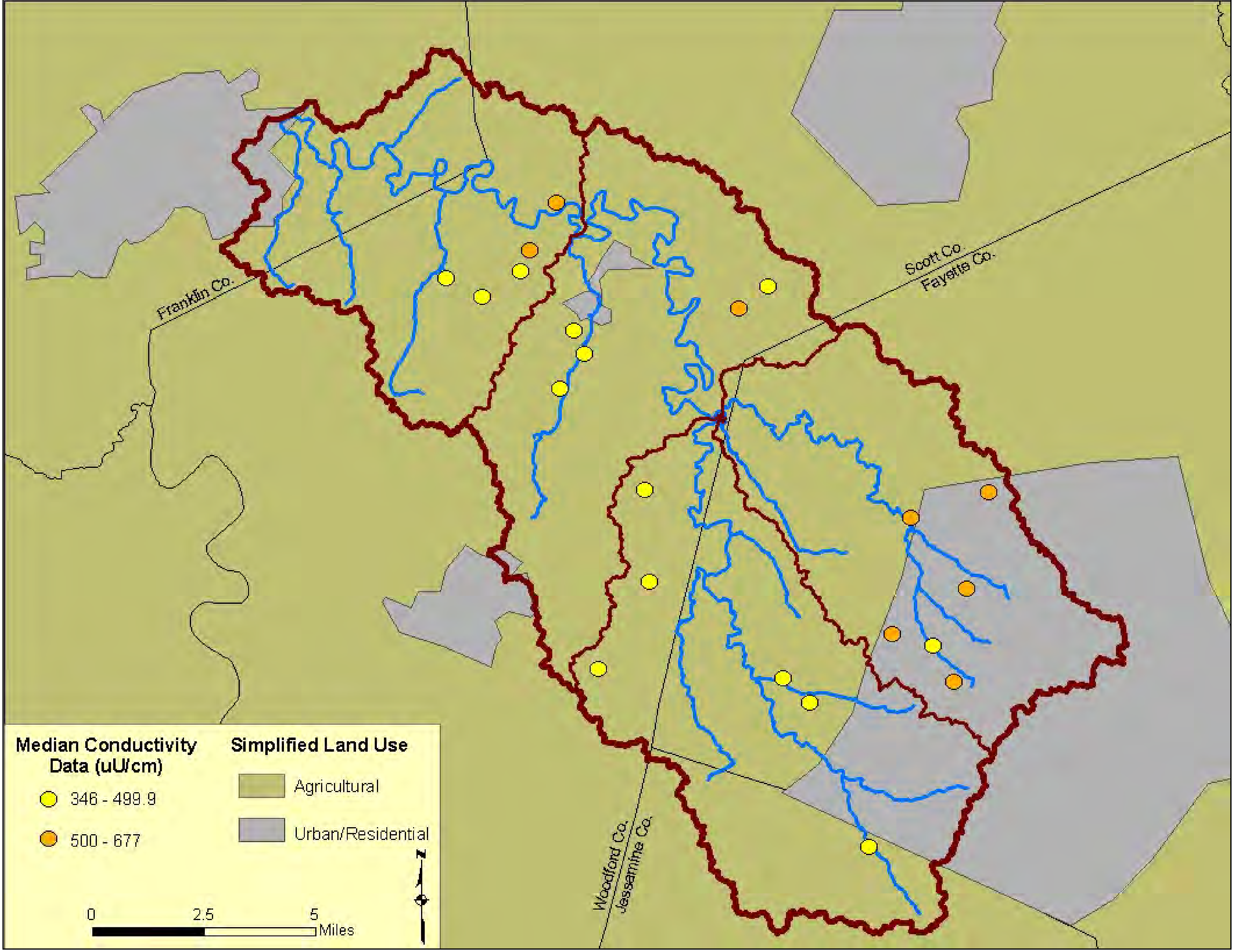
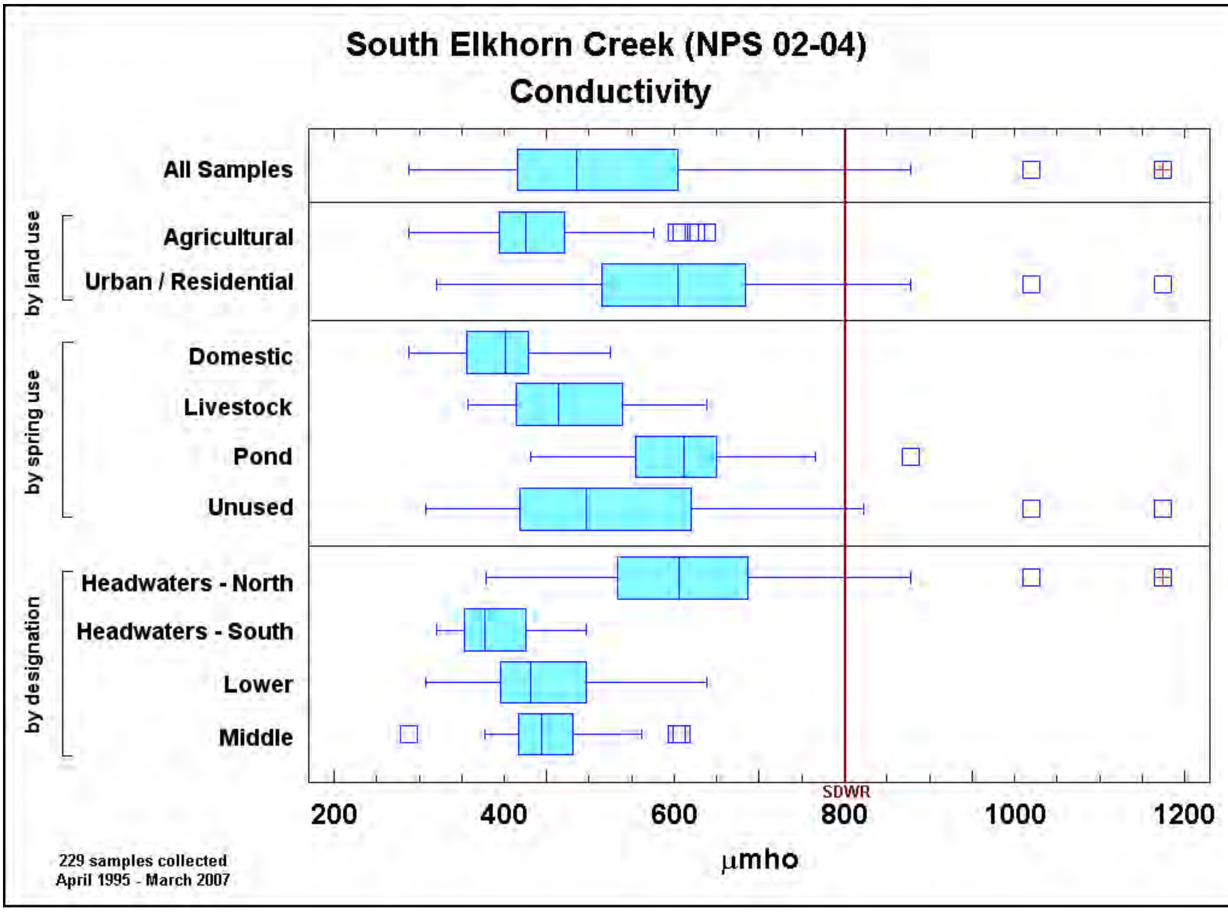


Figure 12. Median Conductivity values for monitored springs in study area



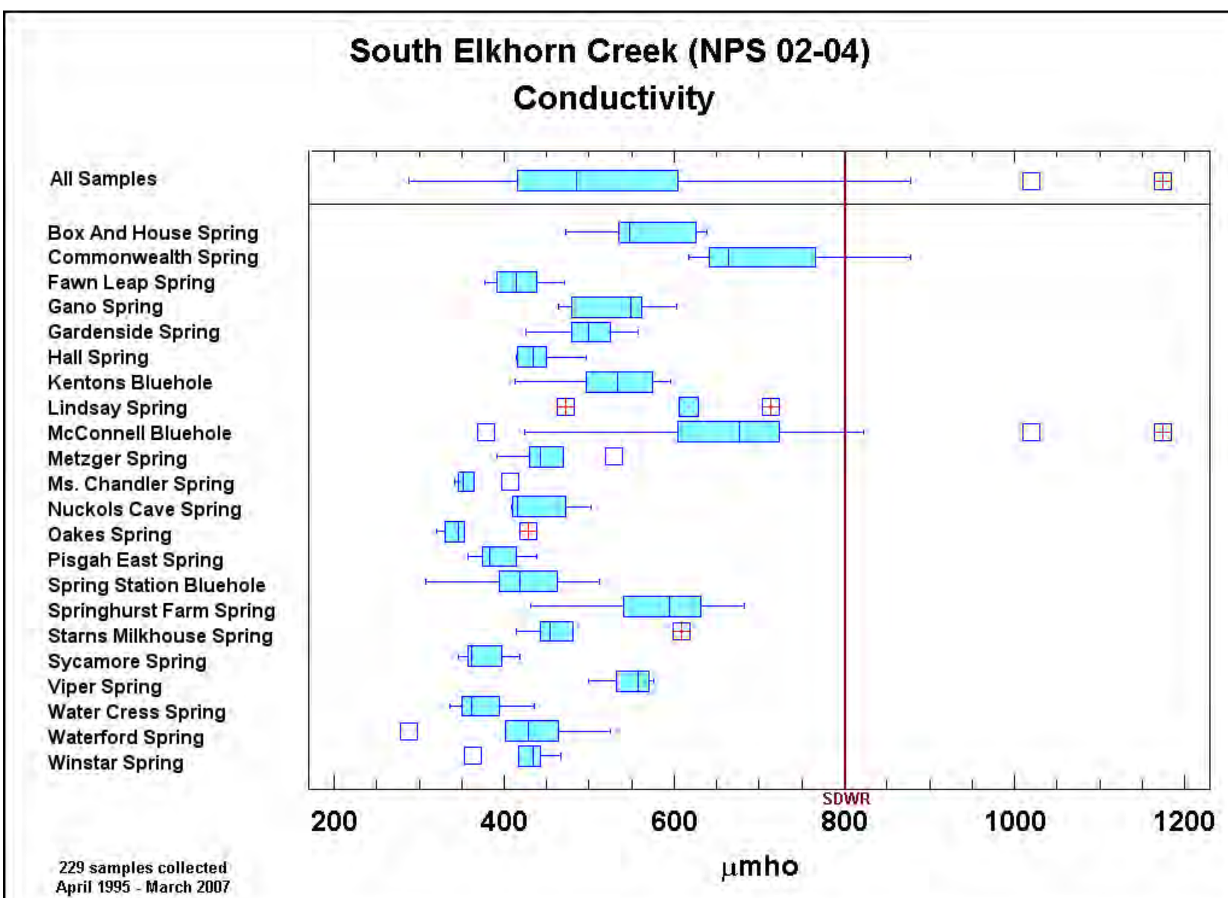
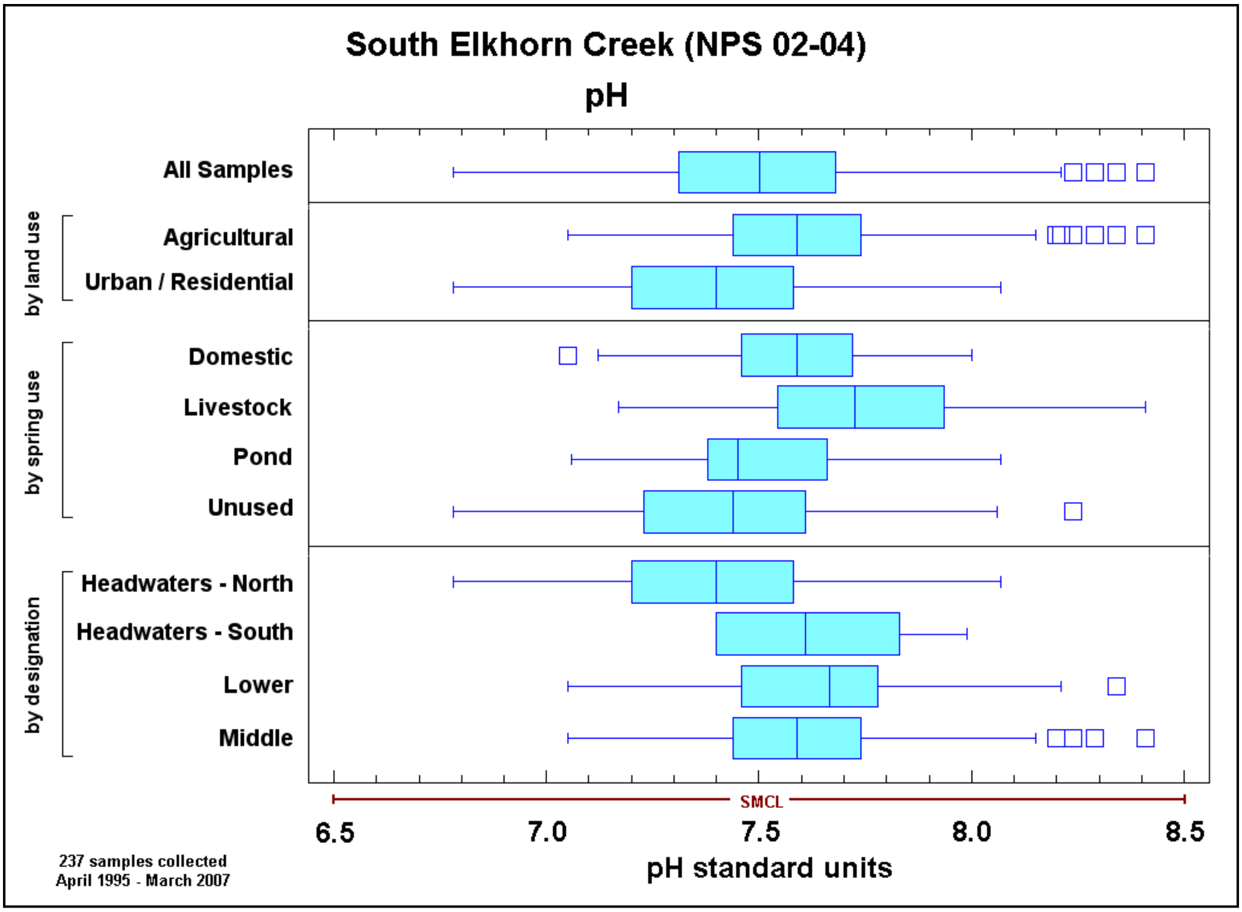


Figure 13. Conductivity Boxplots for monitored springs in study area



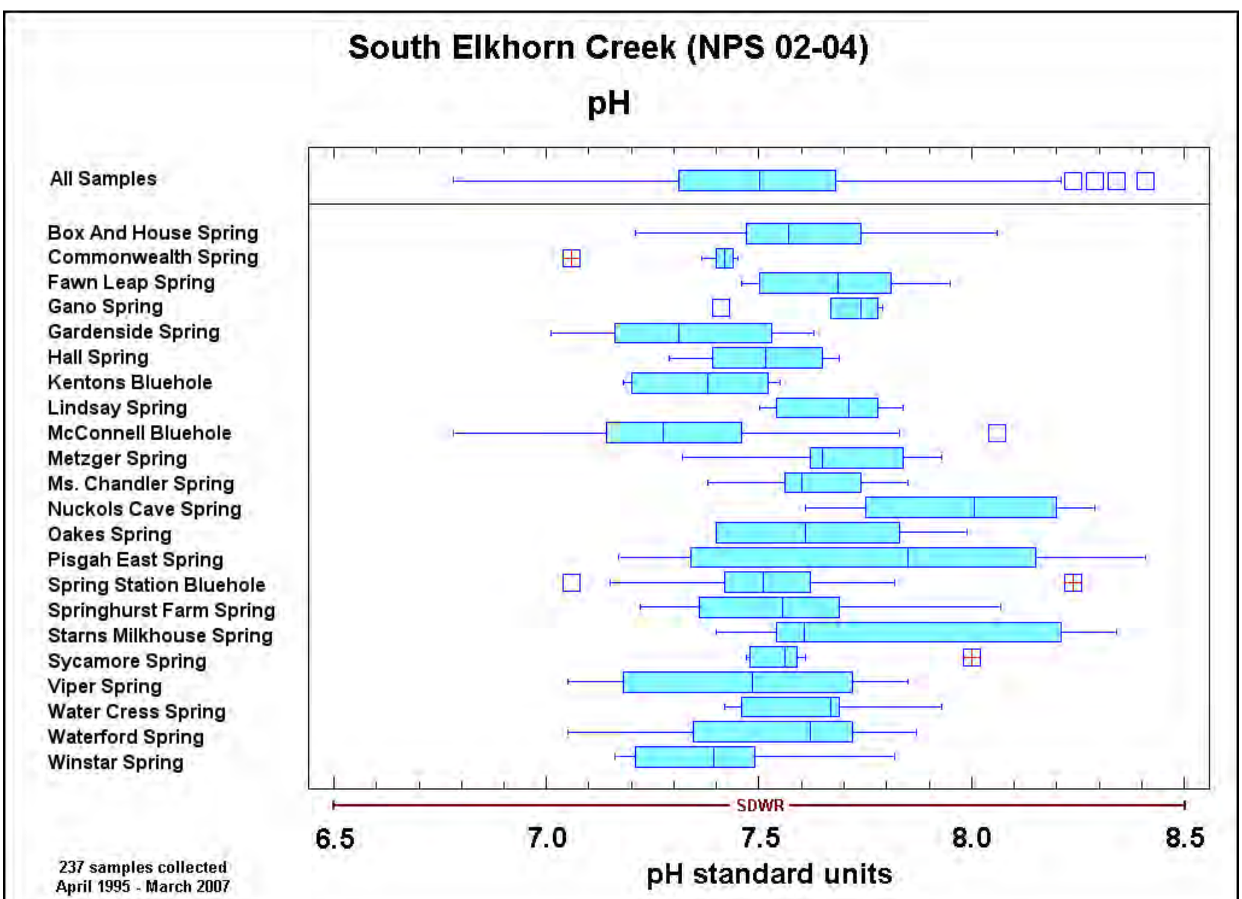


Figure 14. pH Boxplots for monitored springs in study area

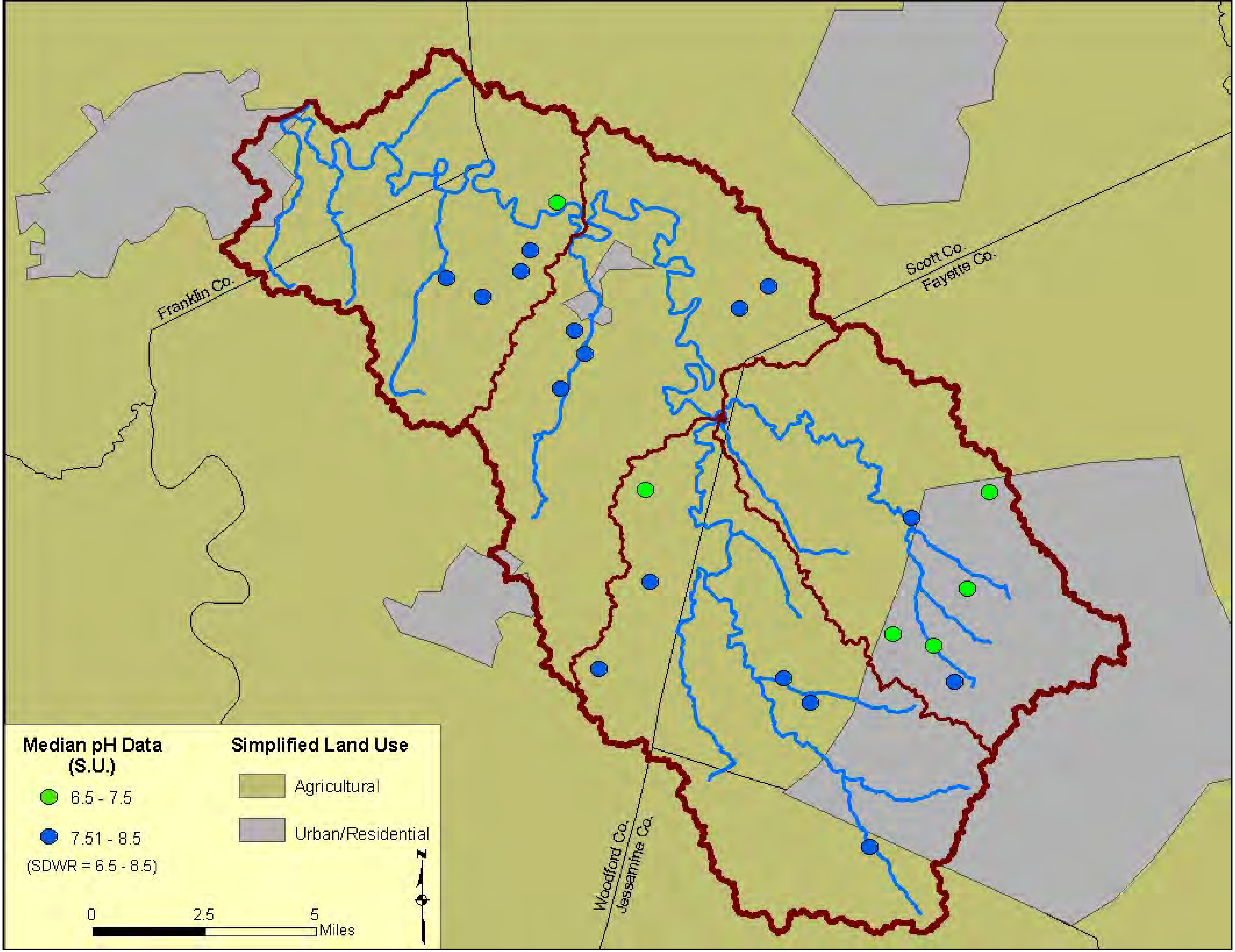
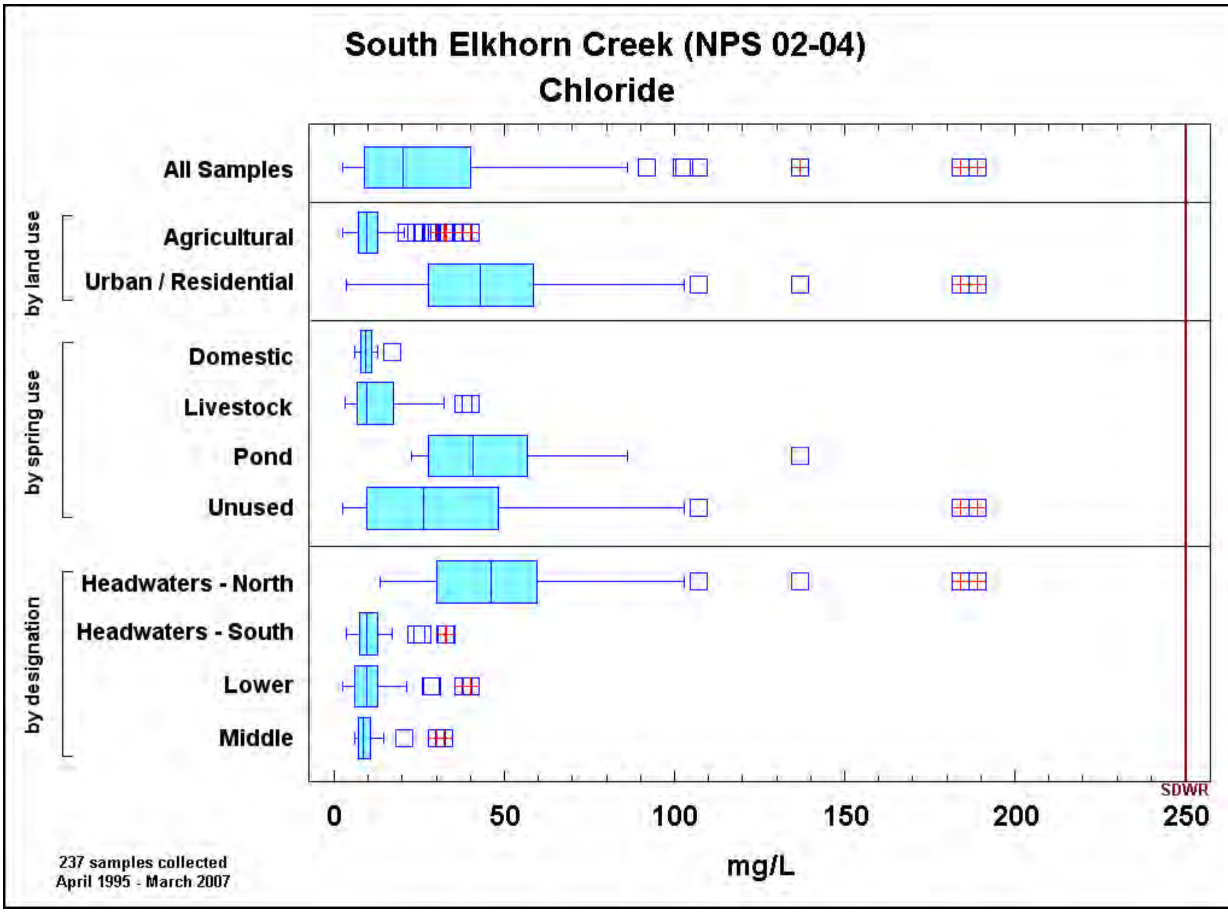


Figure 15. Median pH values for monitored springs in study area compared to SDWR range of 6.5 – 8.5 S.U.



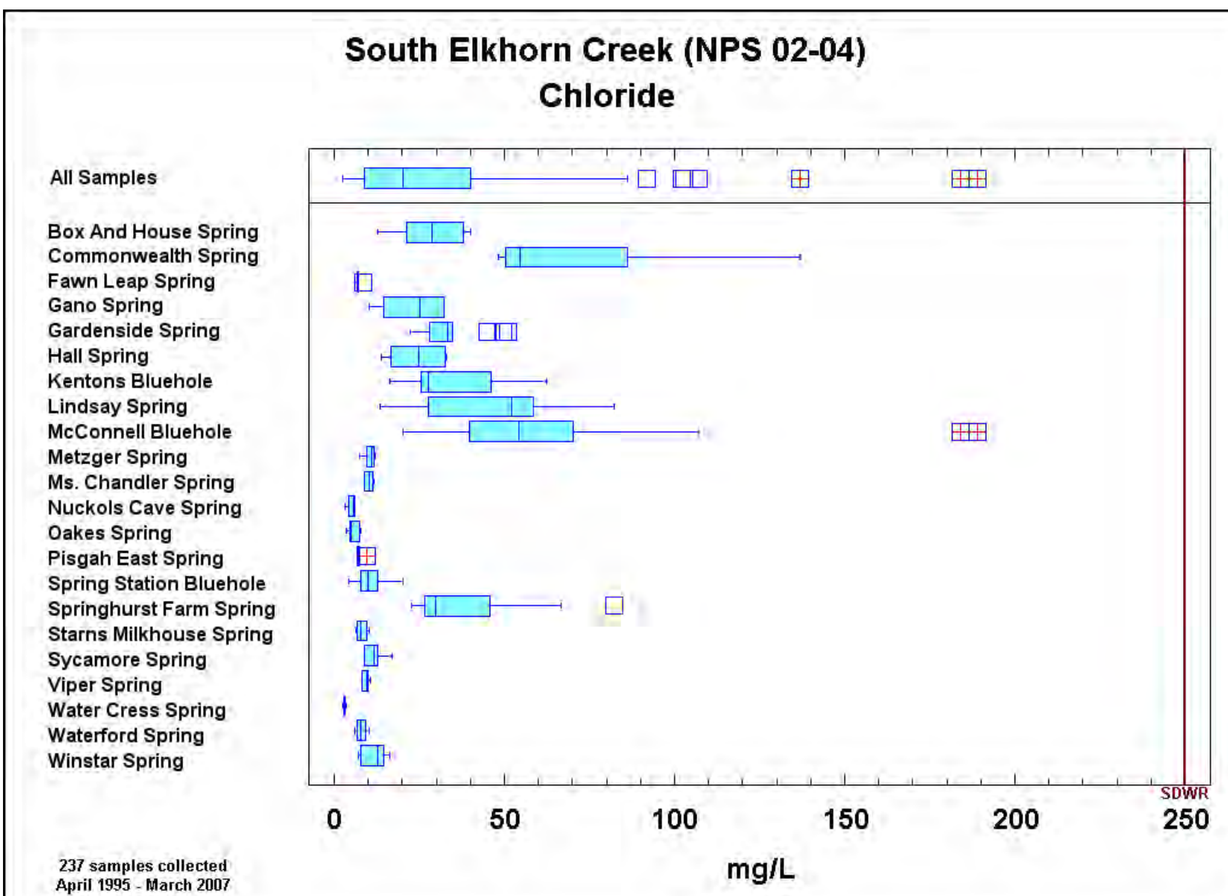


Figure 16. Chloride Boxplots for monitored springs in study area

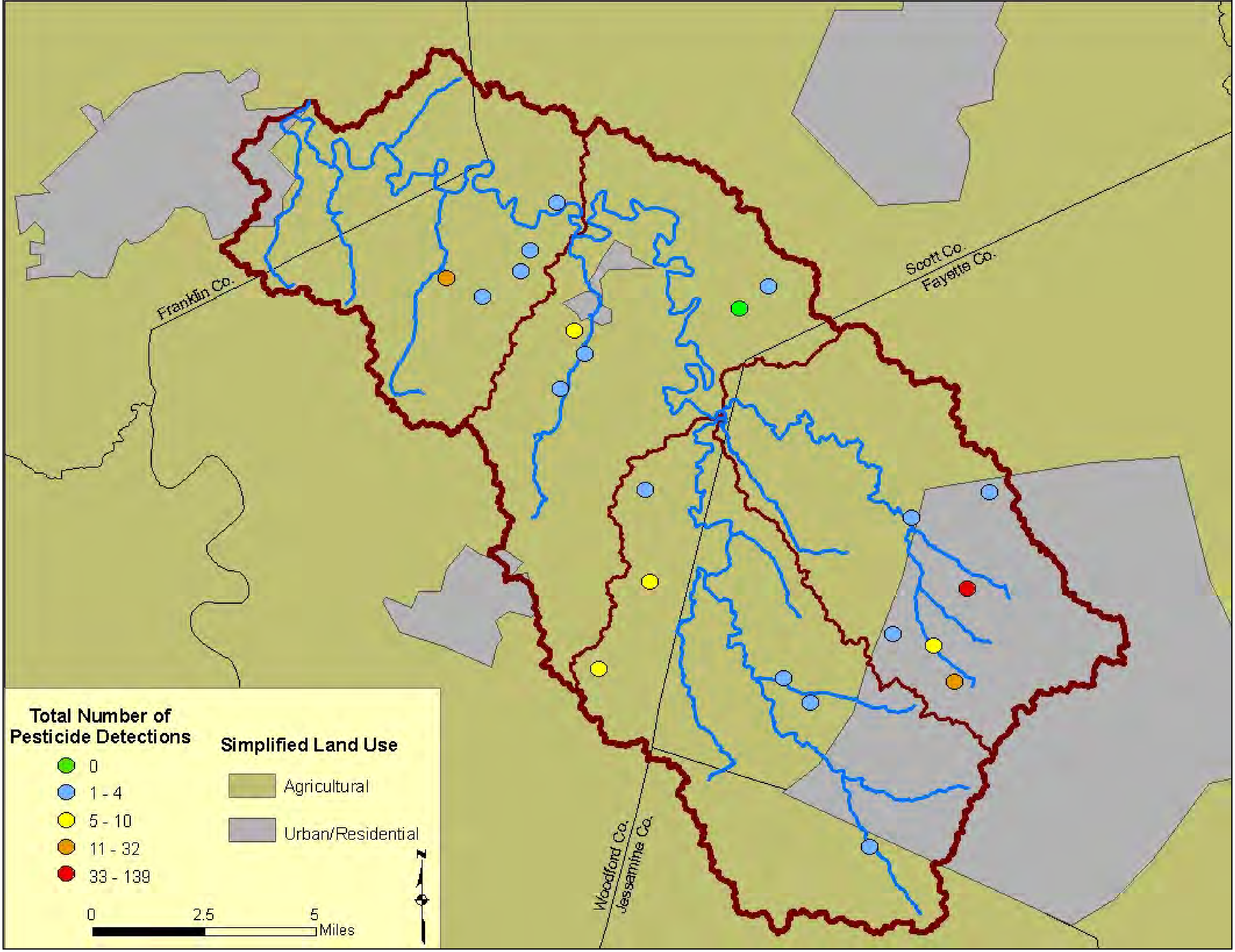


Figure 17. Total number of Pesticide detections at each spring; including historical data, McConnell Spring (red) accounted for 51% of detections

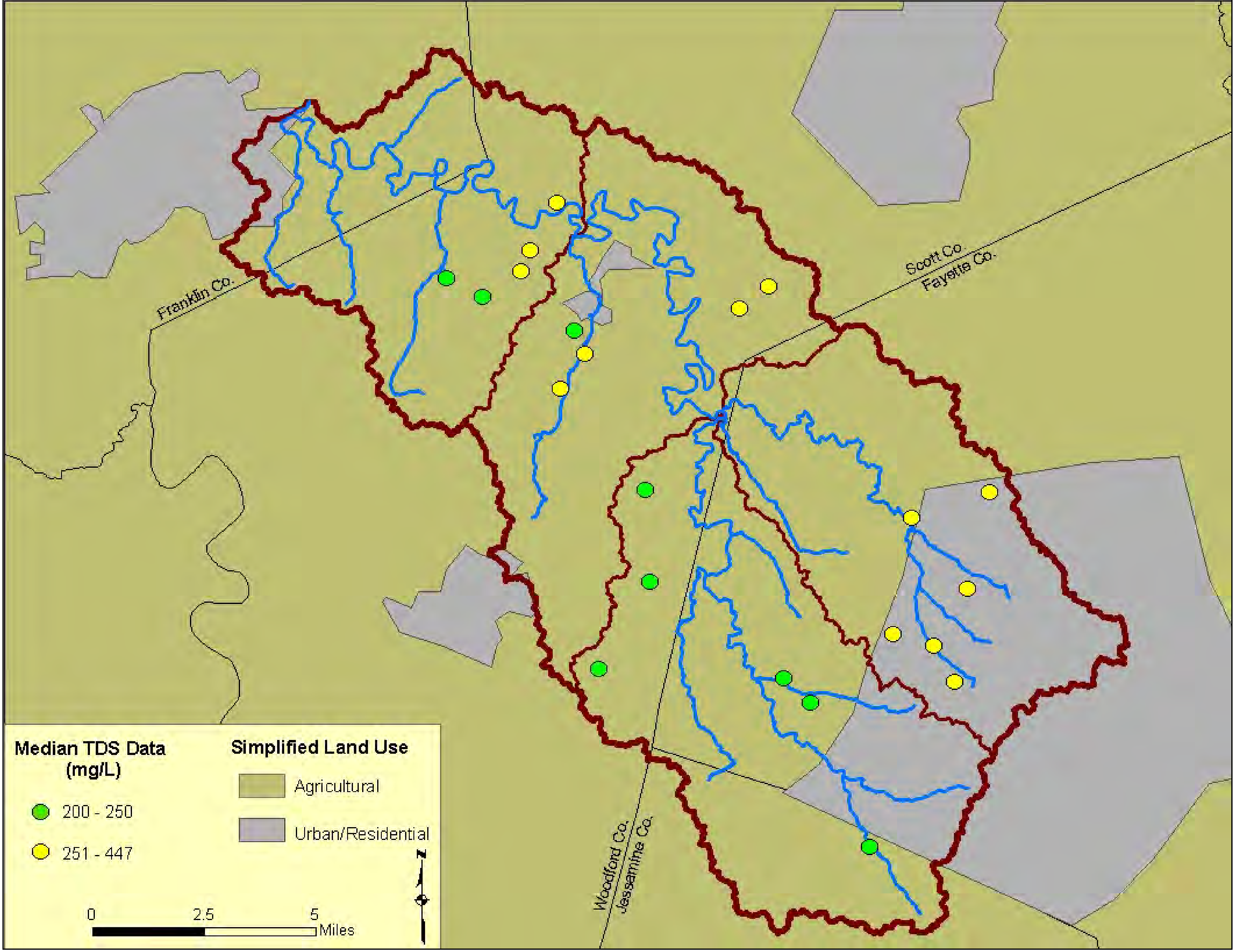


Figure 18. Median Total Dissolved Solids values for monitored springs in study area

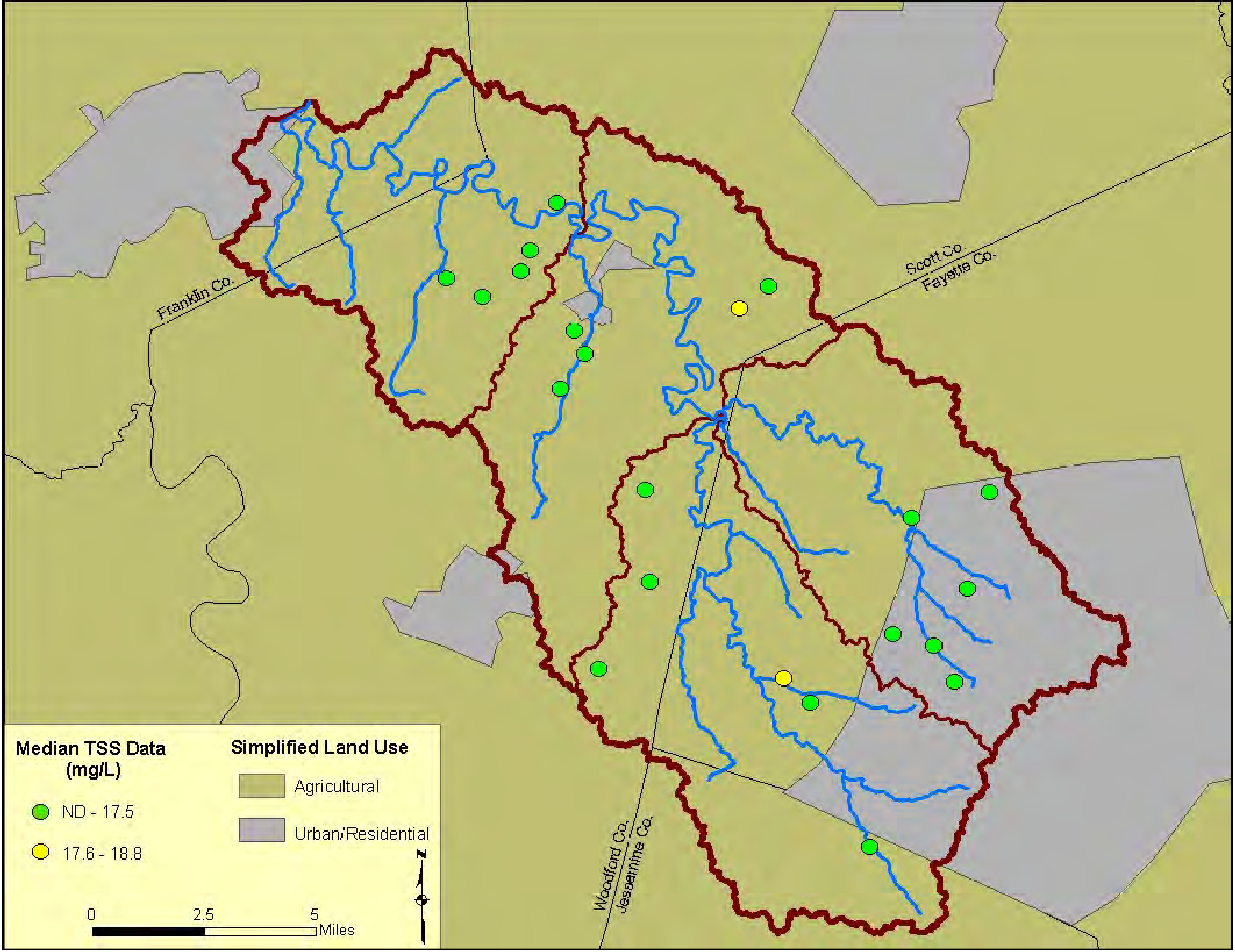
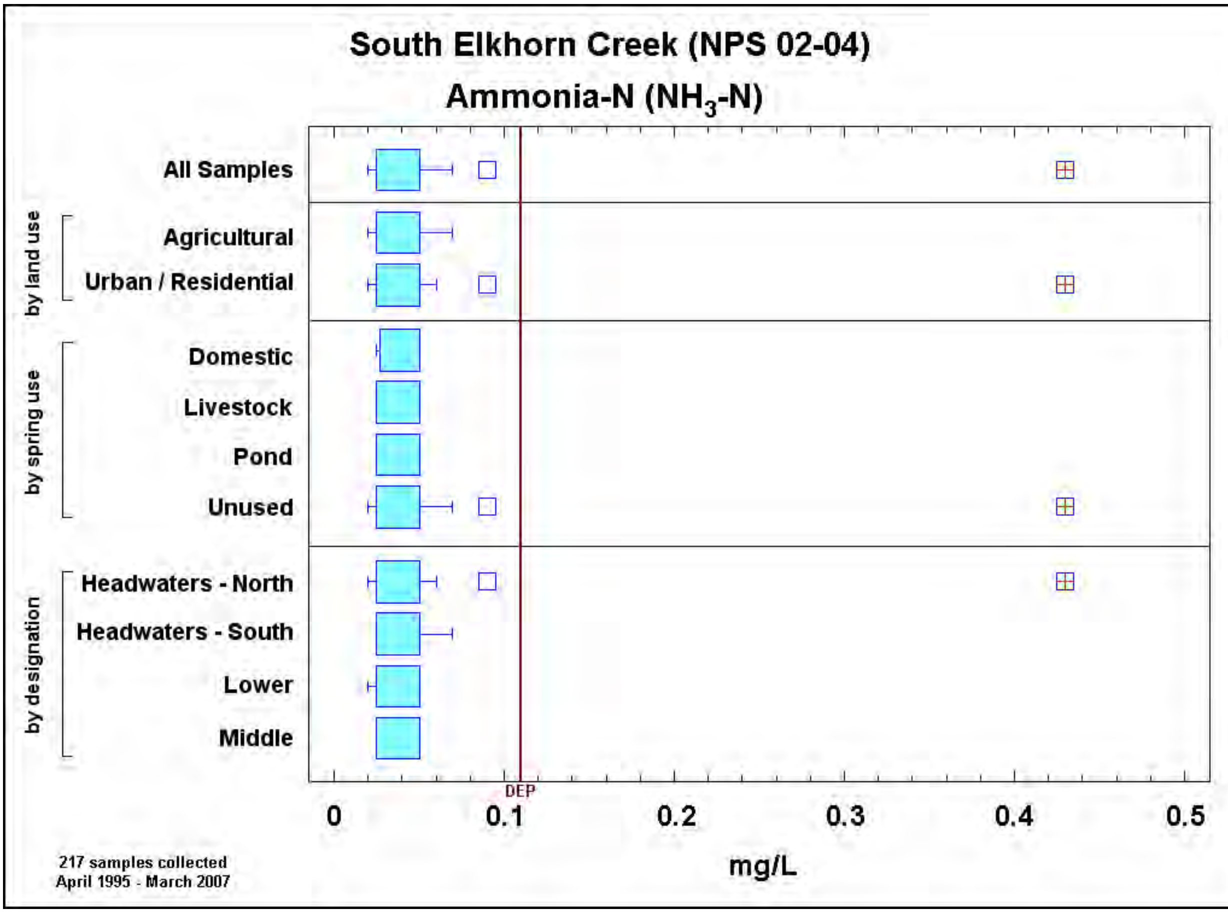


Figure 19. Median Total Suspended Solids values for monitored springs in study area



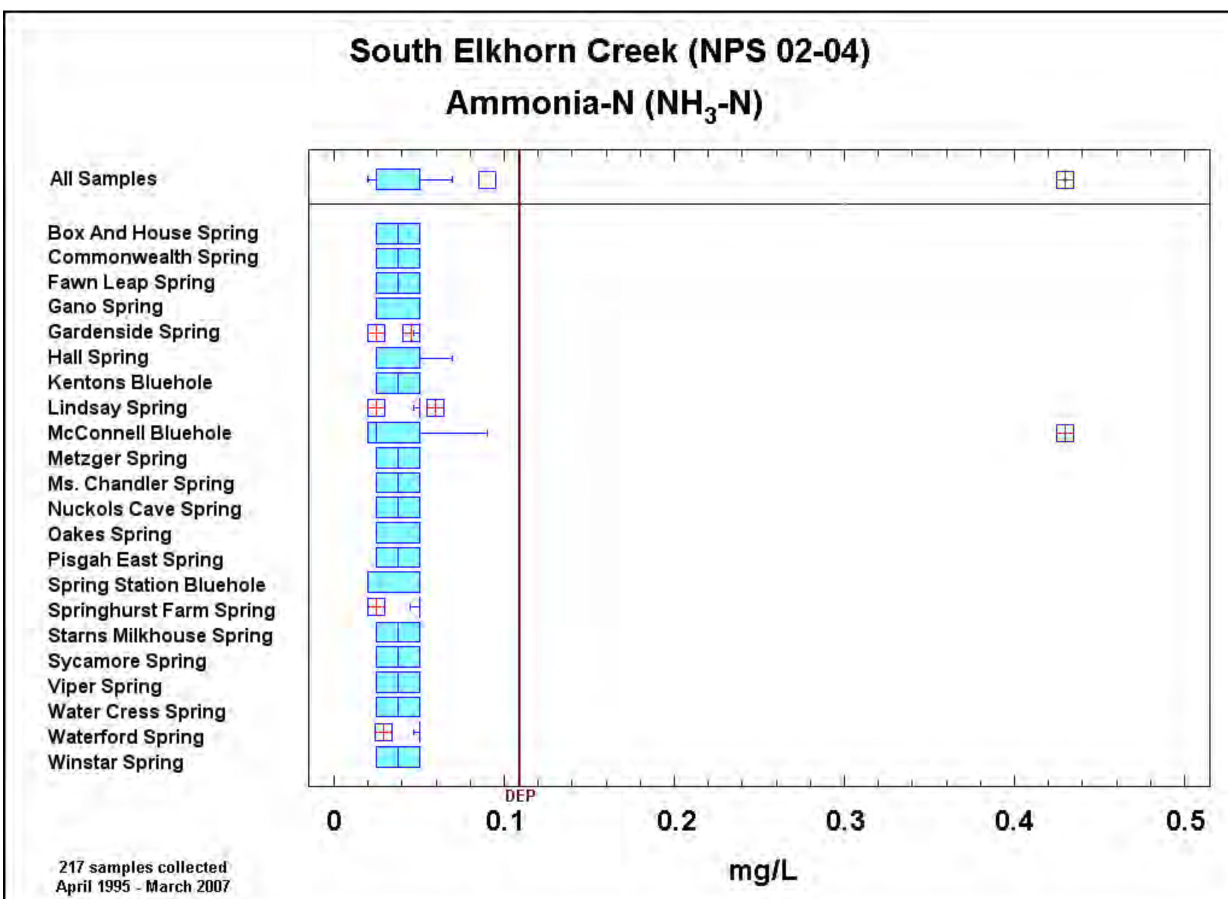
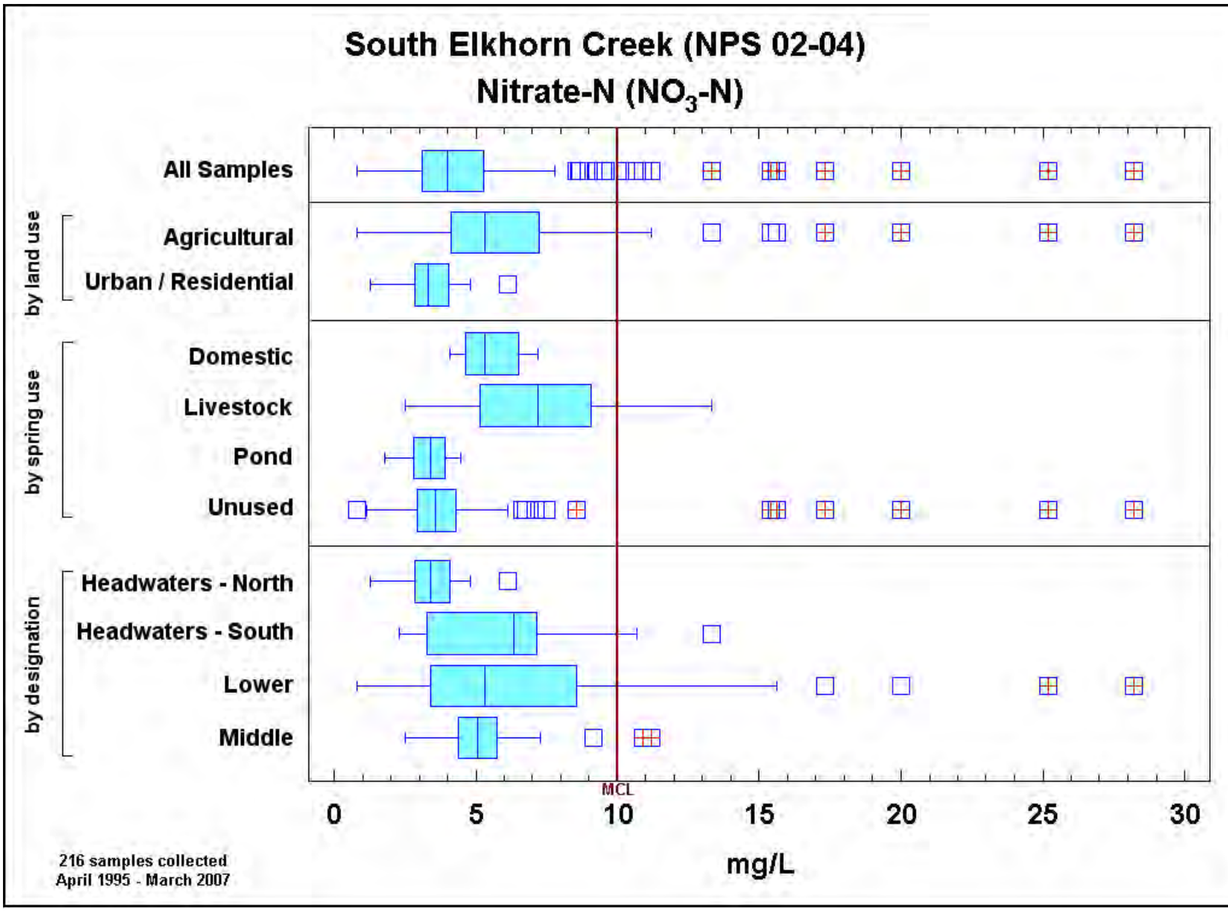


Figure 20. Ammonia-N Boxplots for monitored springs in study area



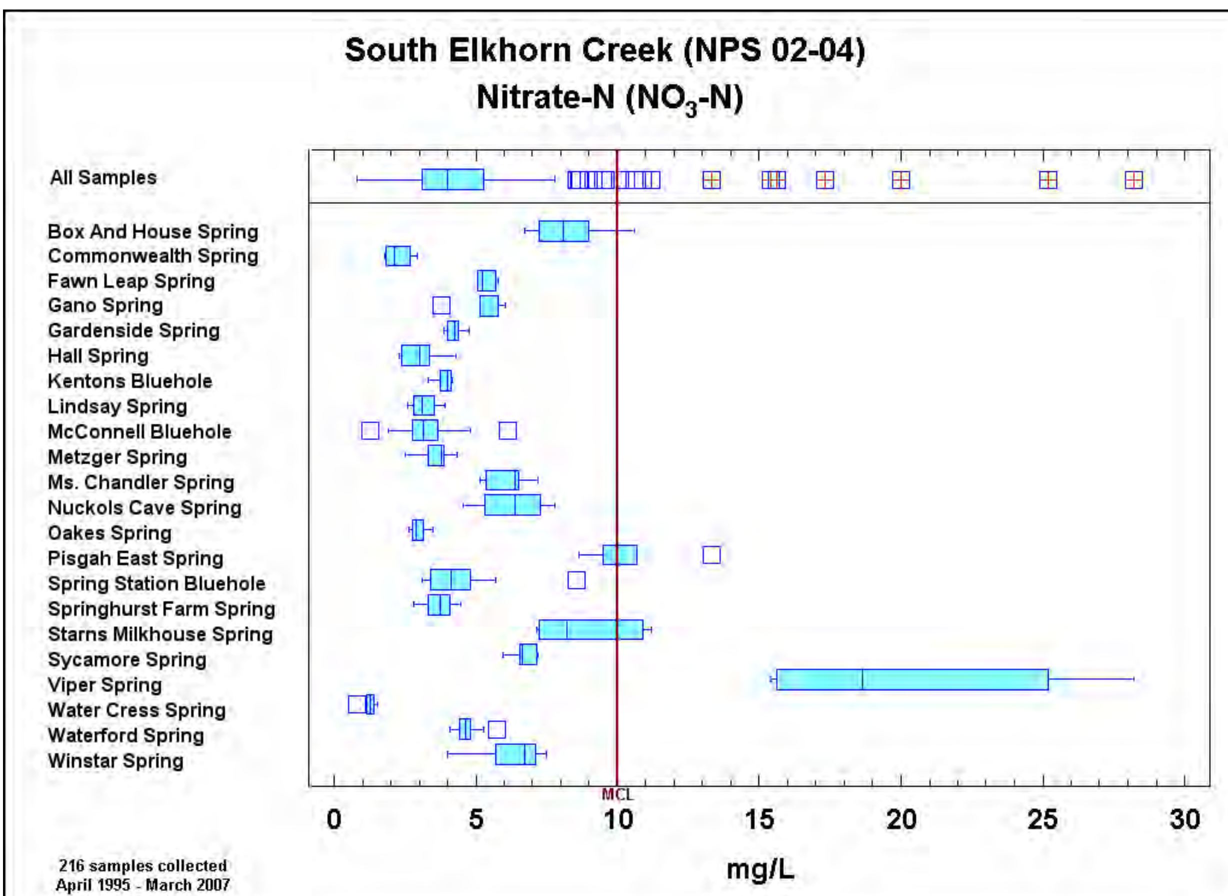


Figure 21. Nitrate-N Boxplots for monitored springs in study area

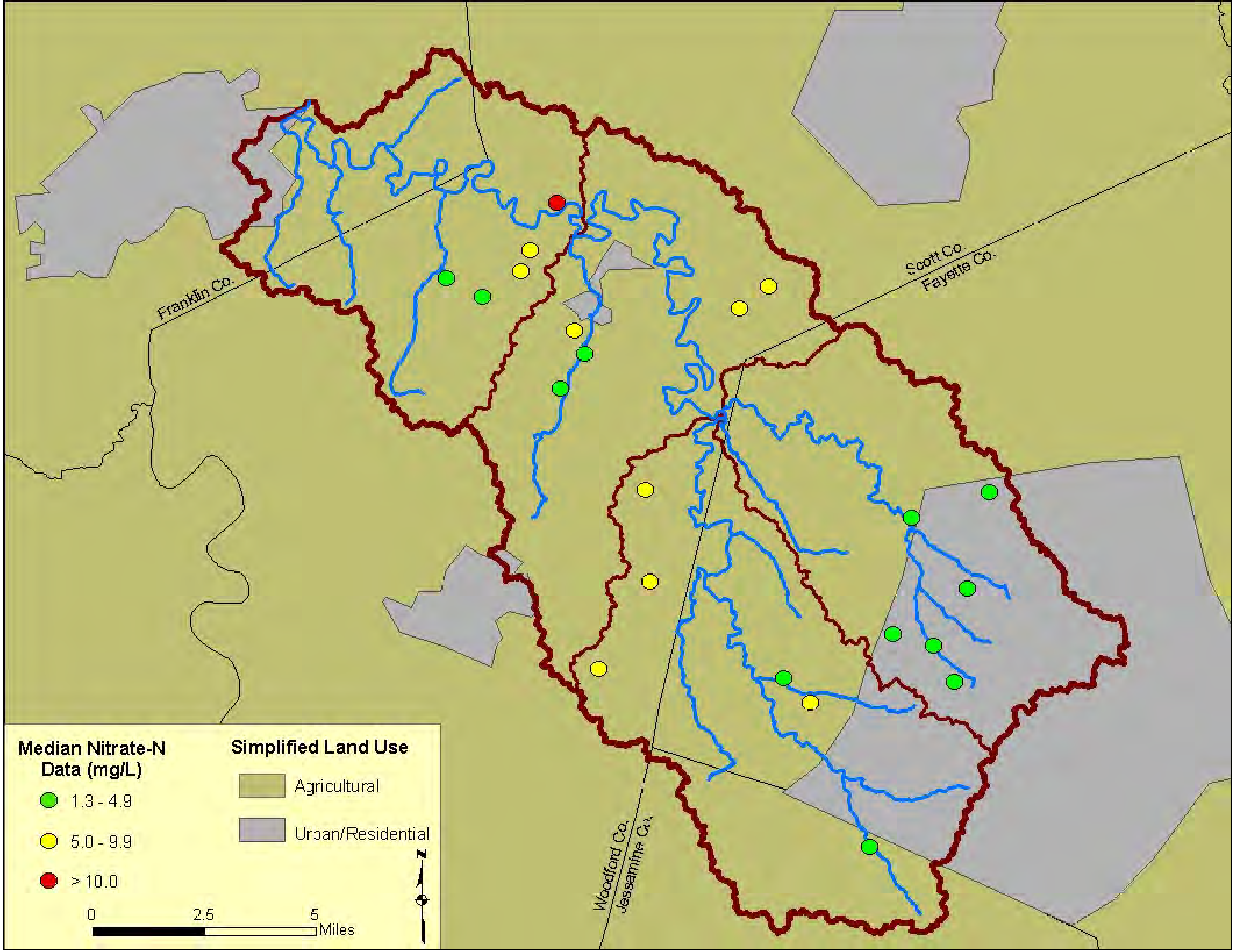
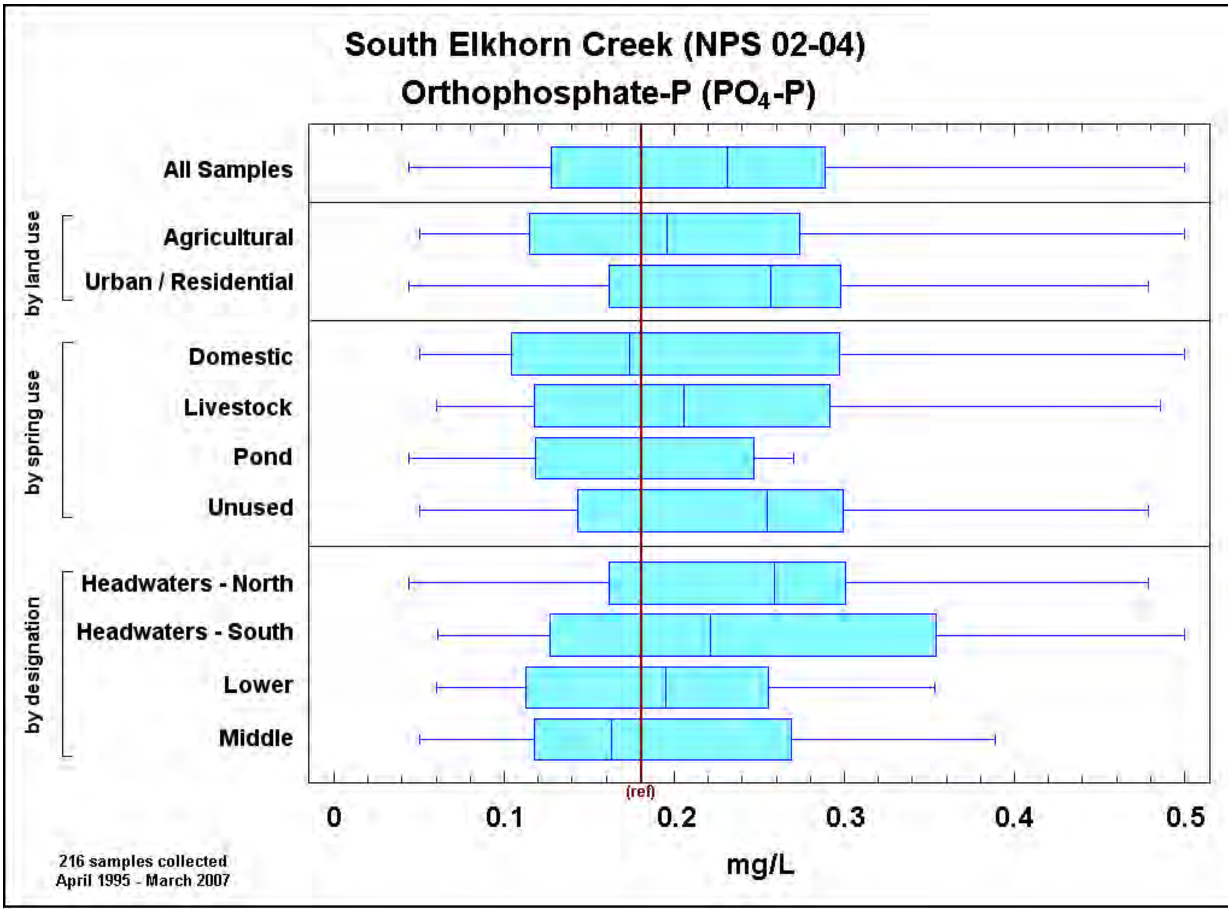


Figure 22. Median Nitrate-N values for monitored springs in study area; Viper Spring (red) was consistently over MCL of 10 mg/L



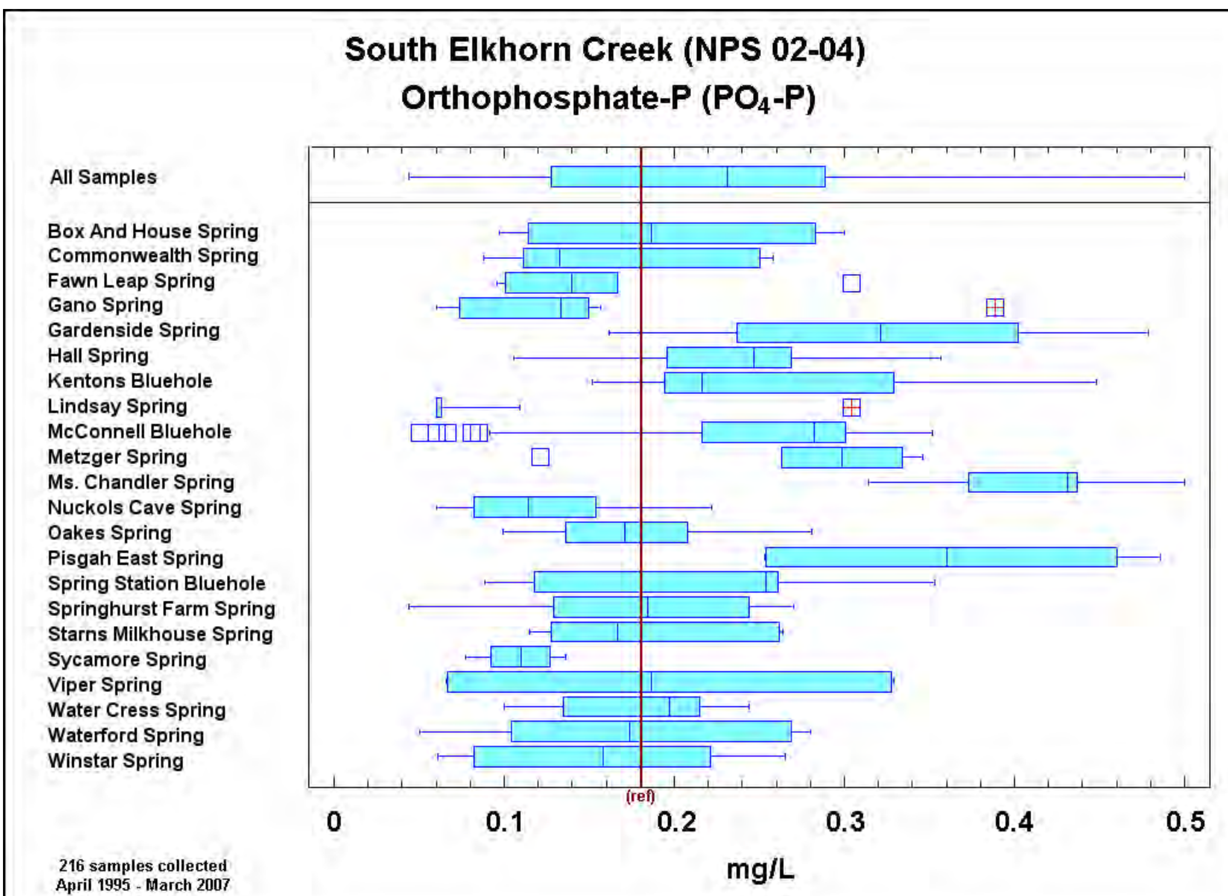


Figure 23. Orthophosphate-P Boxplots for monitored springs in study area

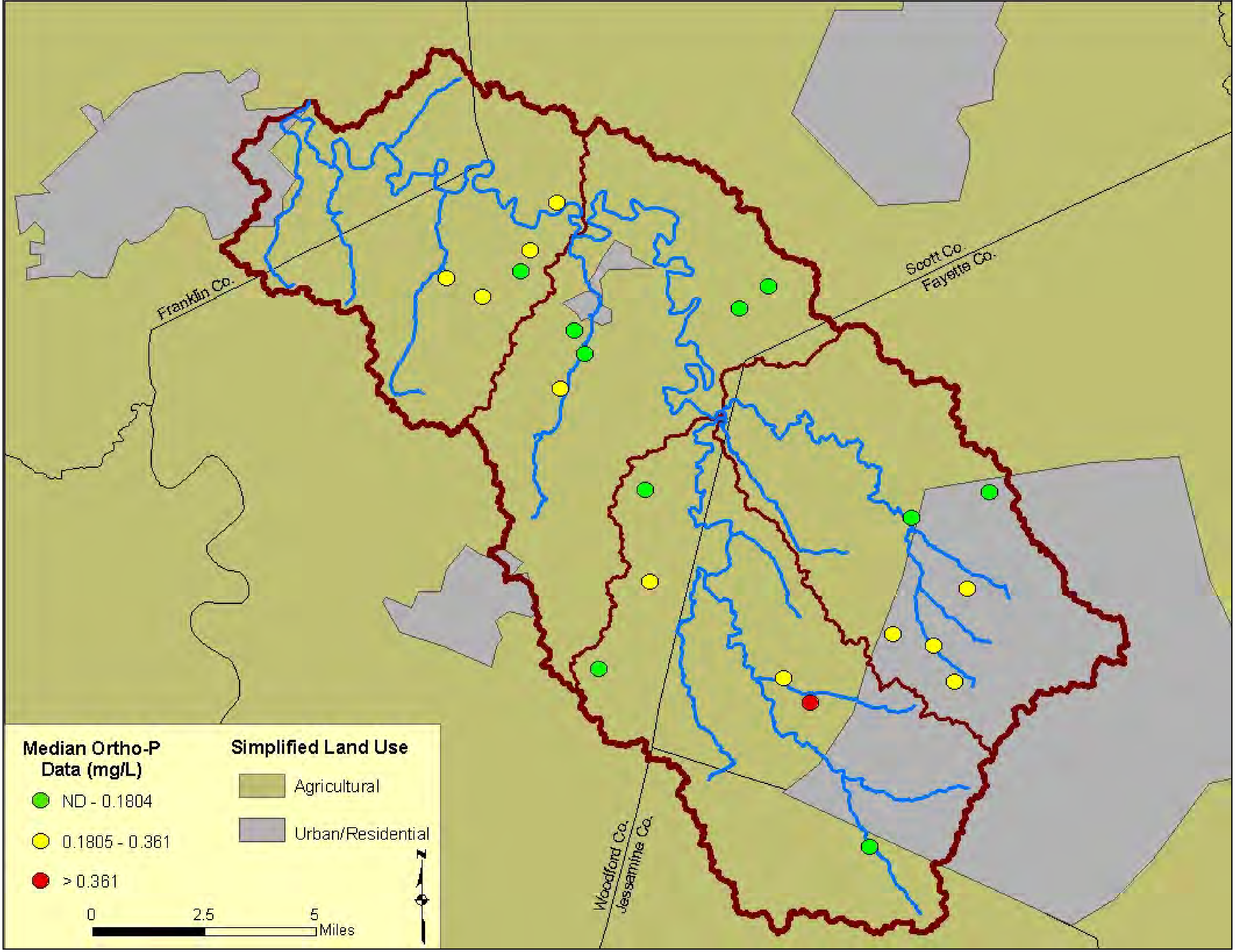
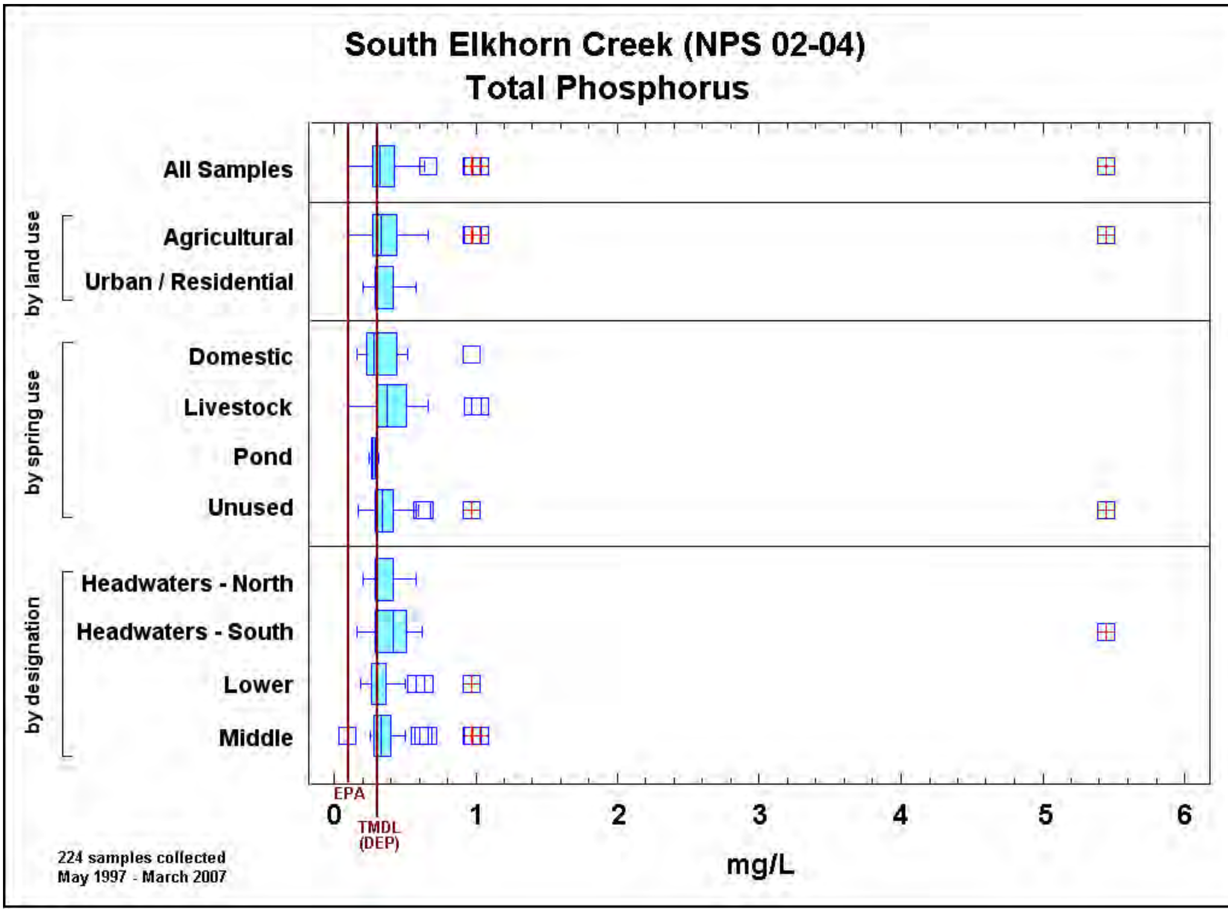


Figure 24. Median Orthophosphate values for monitored springs in study area; Ms. Chandler Spring (red) over reference value



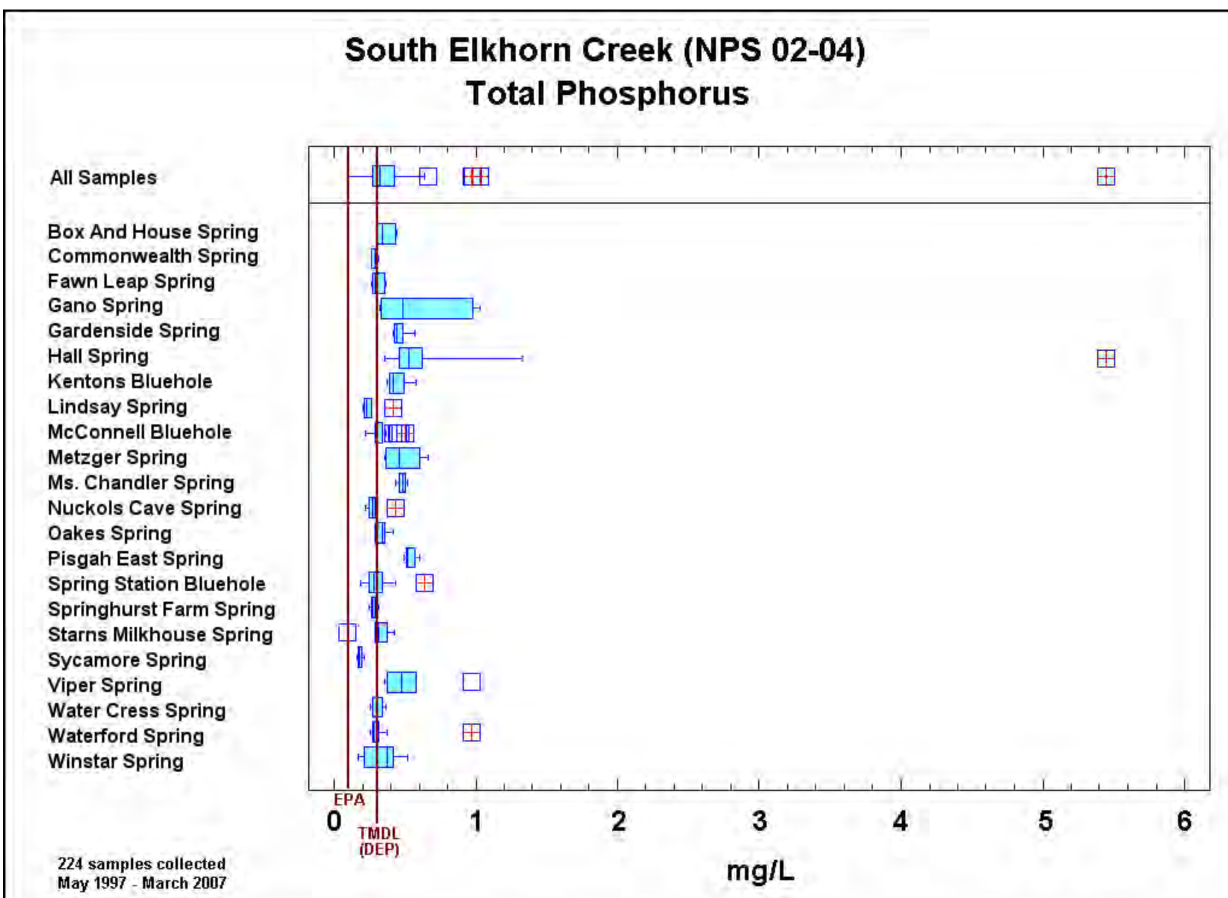


Figure 25. Total Phosphorus Boxplots for monitored springs in study area

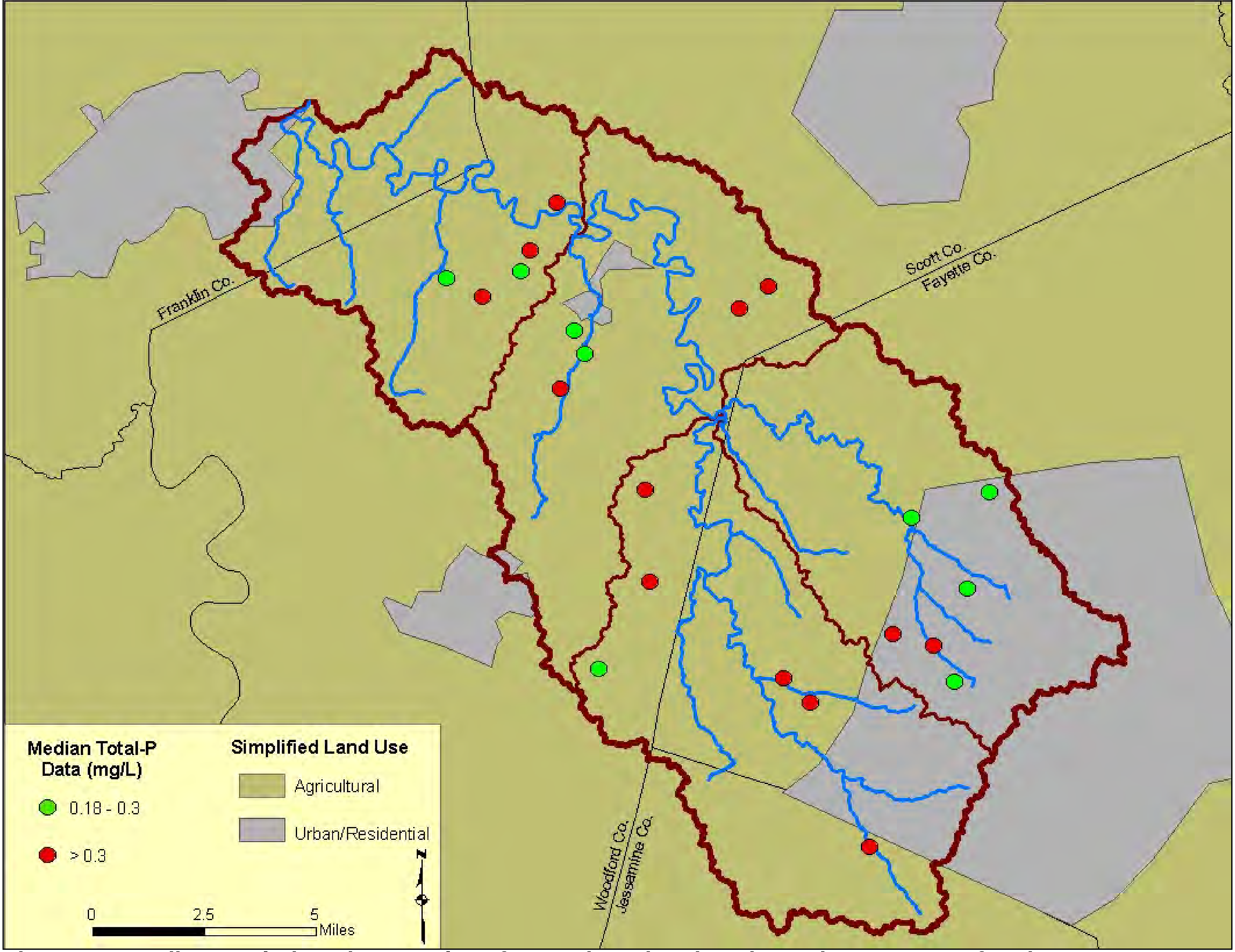


Figure 26. Median Total Phosphorus values for monitored springs in study area; 60% of springs > TMDL Standard of 0.3 mg/L

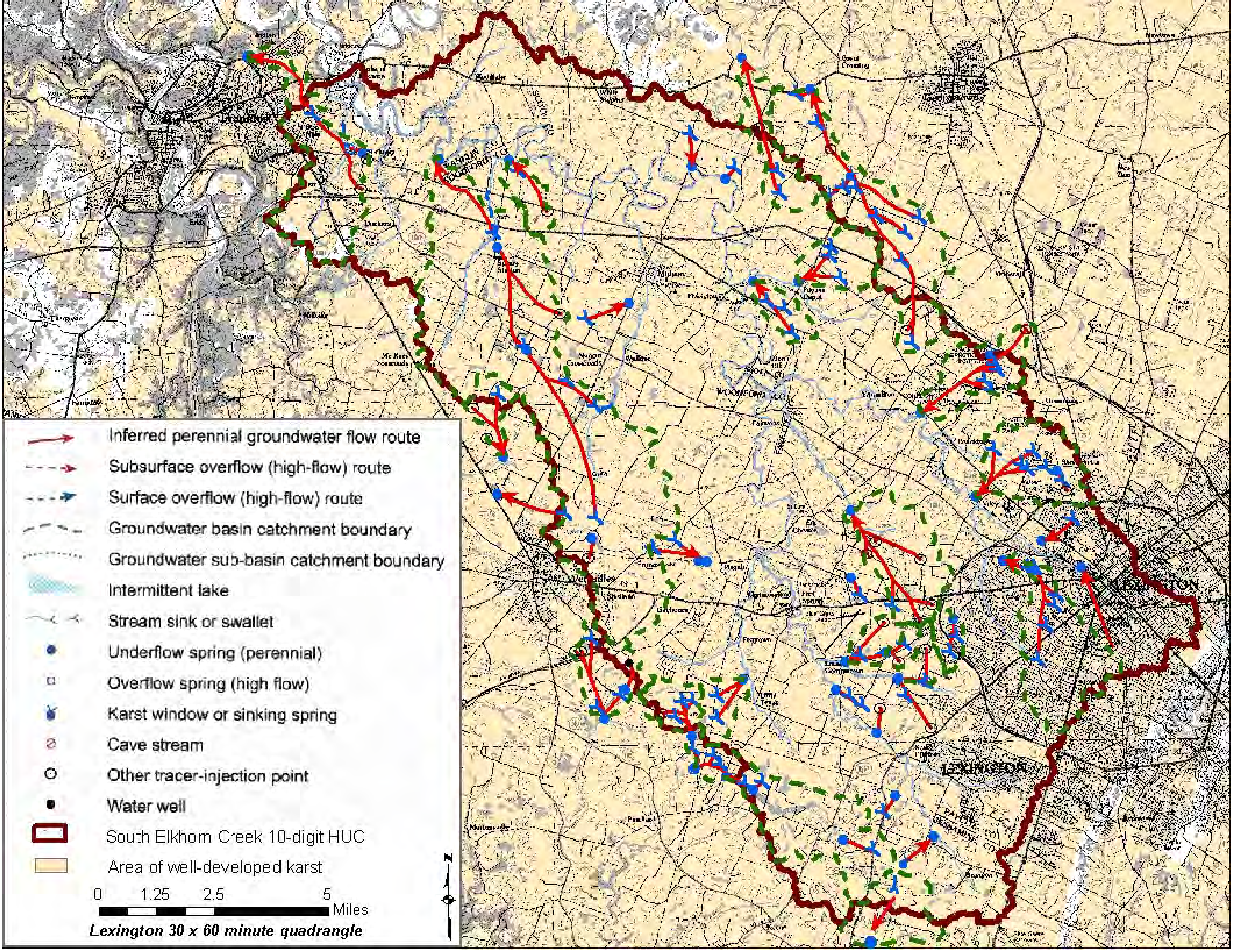
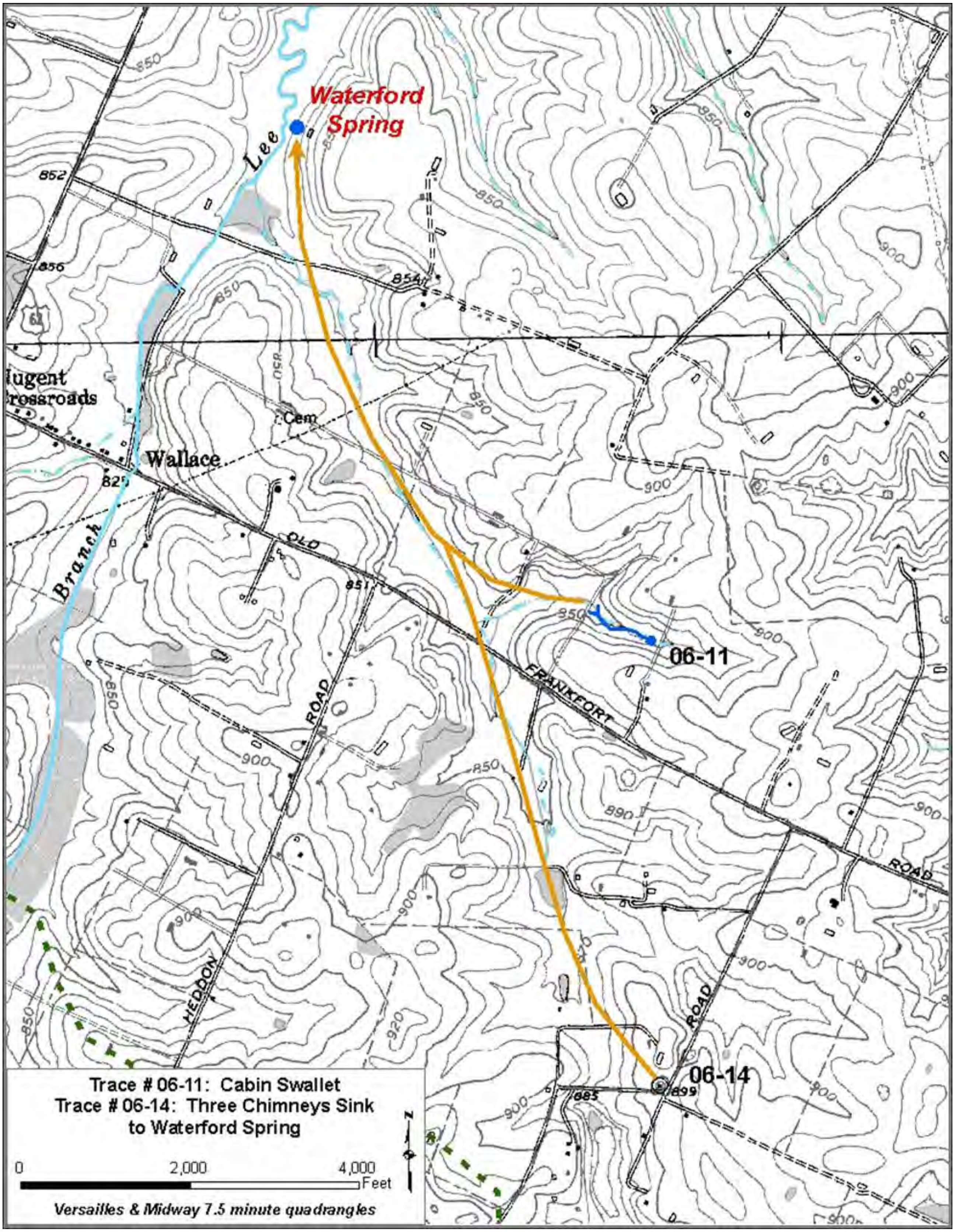
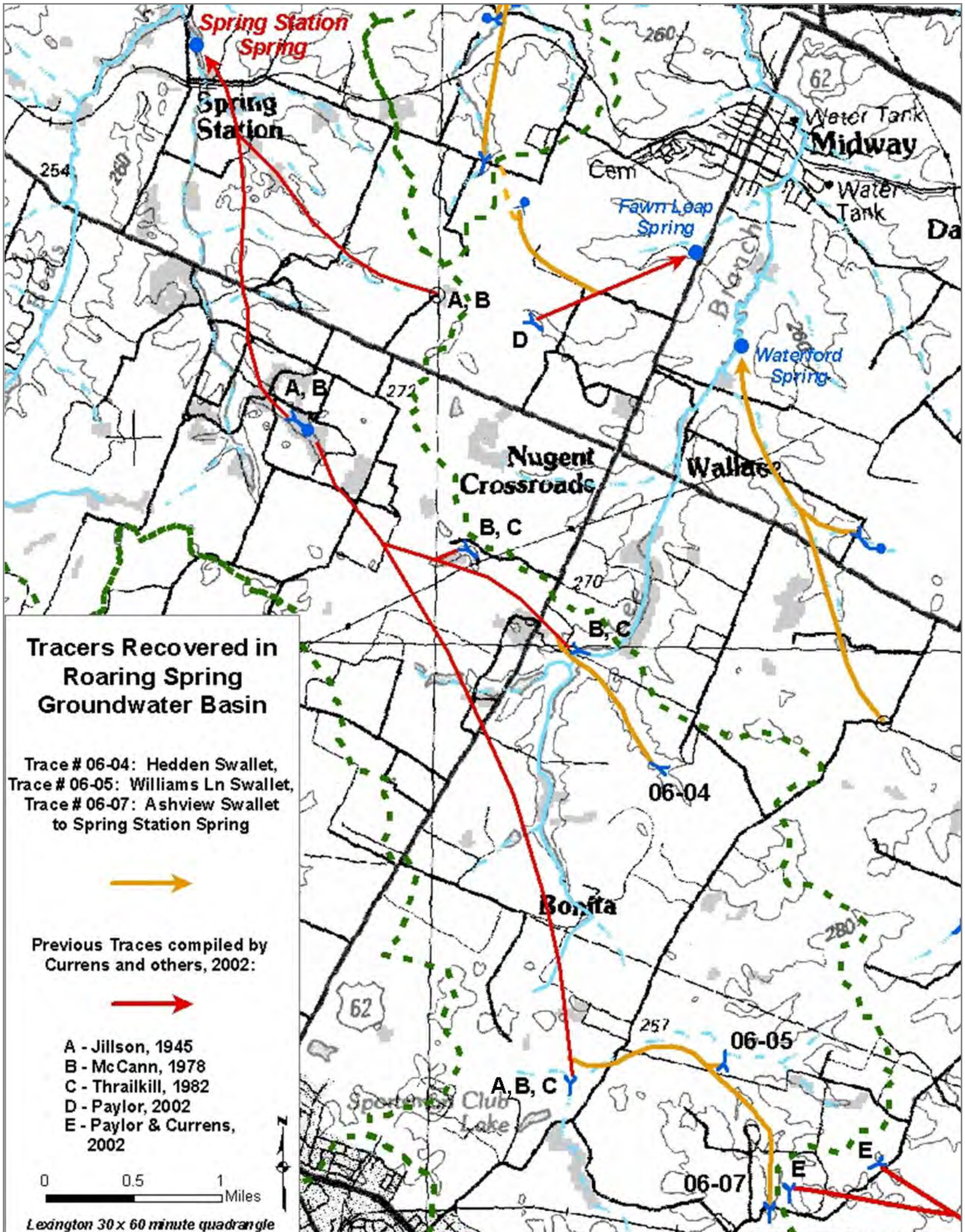


Figure 27. Previous Tracer Tests in South Elkhorn Creek Watershed (from Currens and others, 2002)



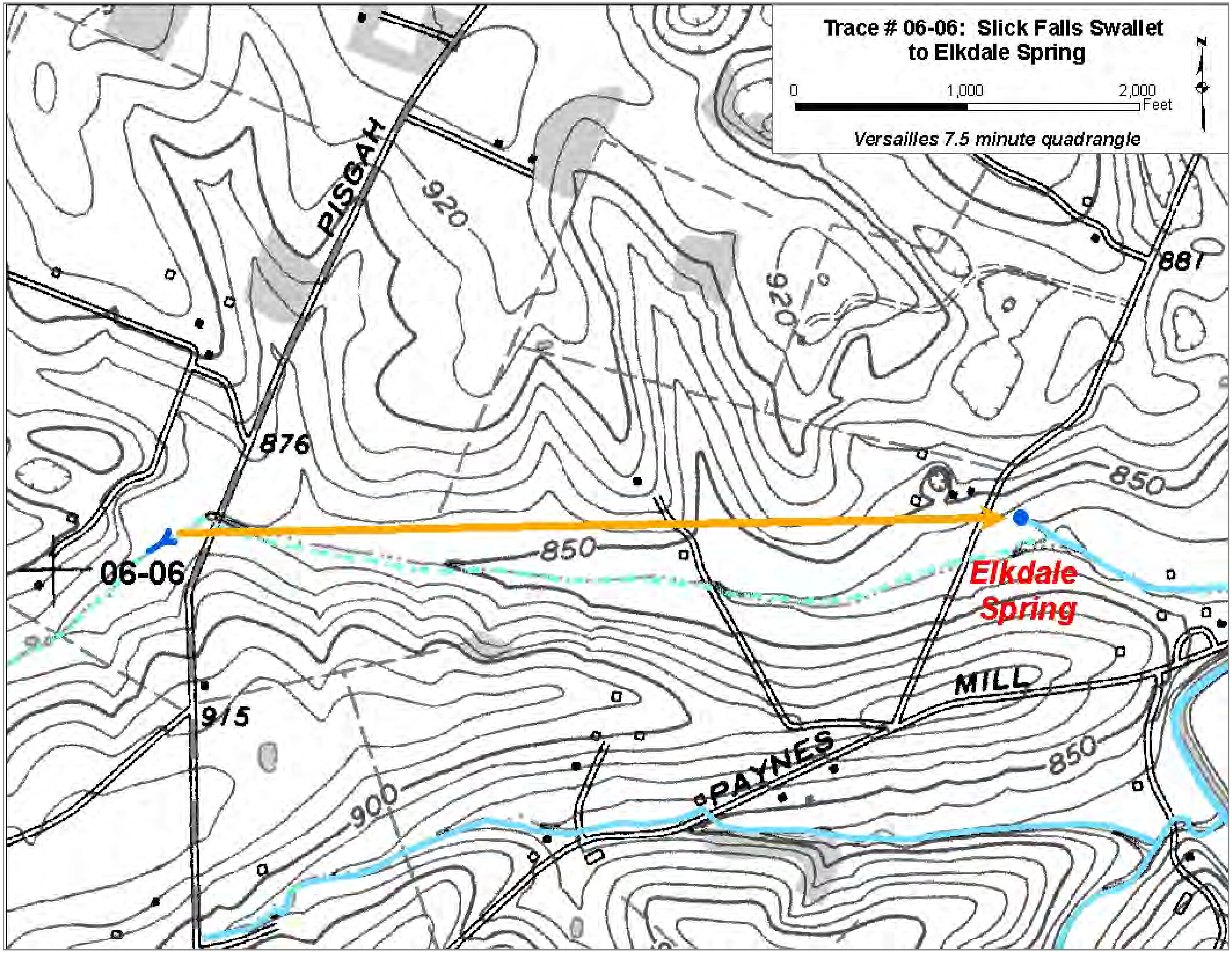
Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Cabin Swallet	Fluor 8/25/06 06-11	0.25 oz	0.01	No	Waterford Sp (+++) 8/29/06	**7337**	**> 1834**
Three Chimneys Sink	SRB 9/26/06 06-14	5 oz		Yes-200 gallons	Waterford Sp (++) 10/12/06 Replication of 06-09	**12,291**	**> 774**

Figure 28. Tracer Data for Waterford Spring



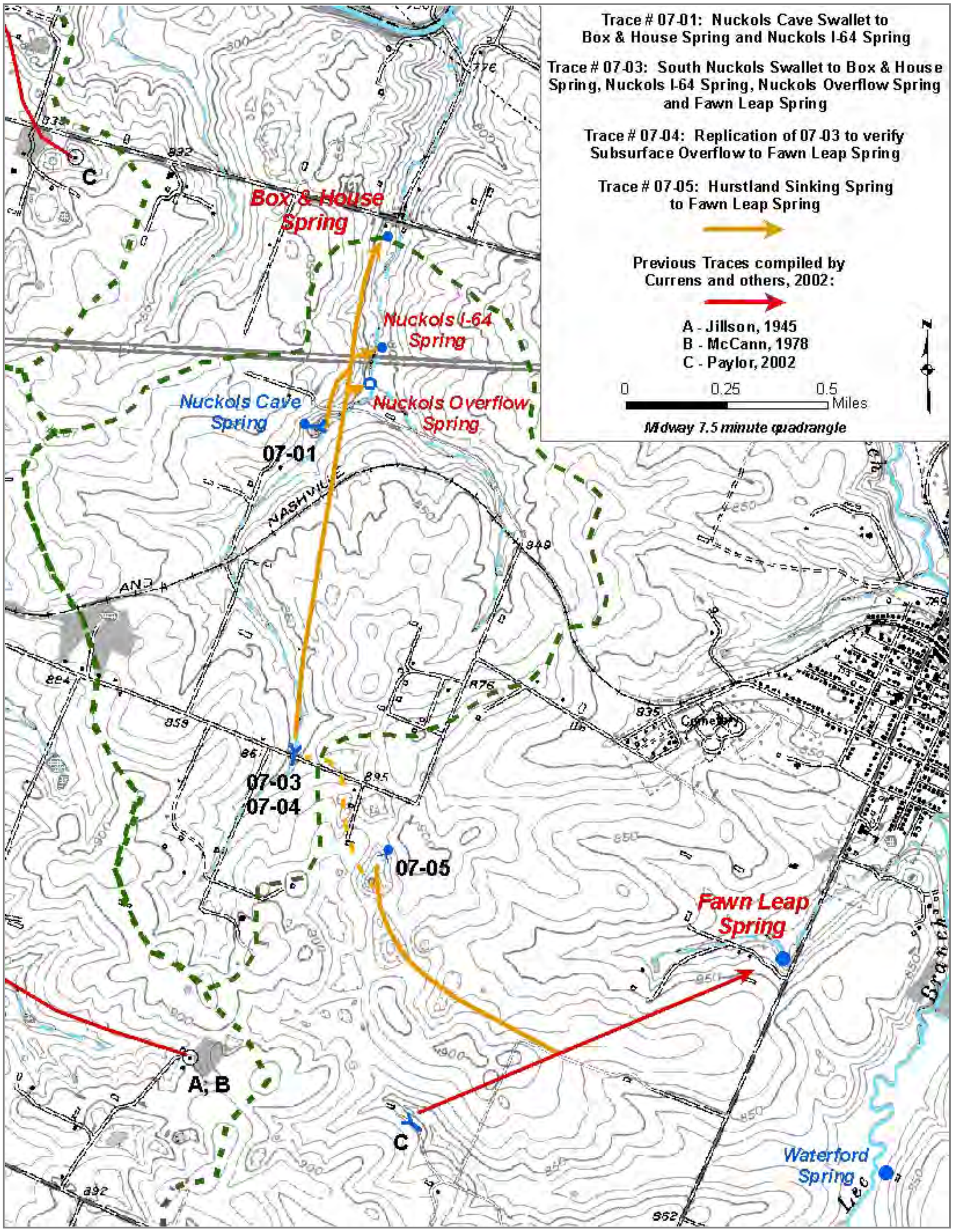
Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Hedden Swallet	SRB 4/18/06 06-04	2 oz	0.01	Yes-0.05 cfs for 10 min	Spring Station (+) 4/24/06	**27,623**	**> 4604**
Williams Ln Swallet	Eosine 4/18/06 06-05	5 oz	0.05	No	Spring Station (++) 4/24/06	**38,152**	**> 6403**
Ashview Swallet	SRB 5/15/06 06-07	2 oz	0.05	No	Spring Station (+) 5/22/06	**42,805**	**> 6115**

Figure 29. Tracer Data for Spring Station Spring



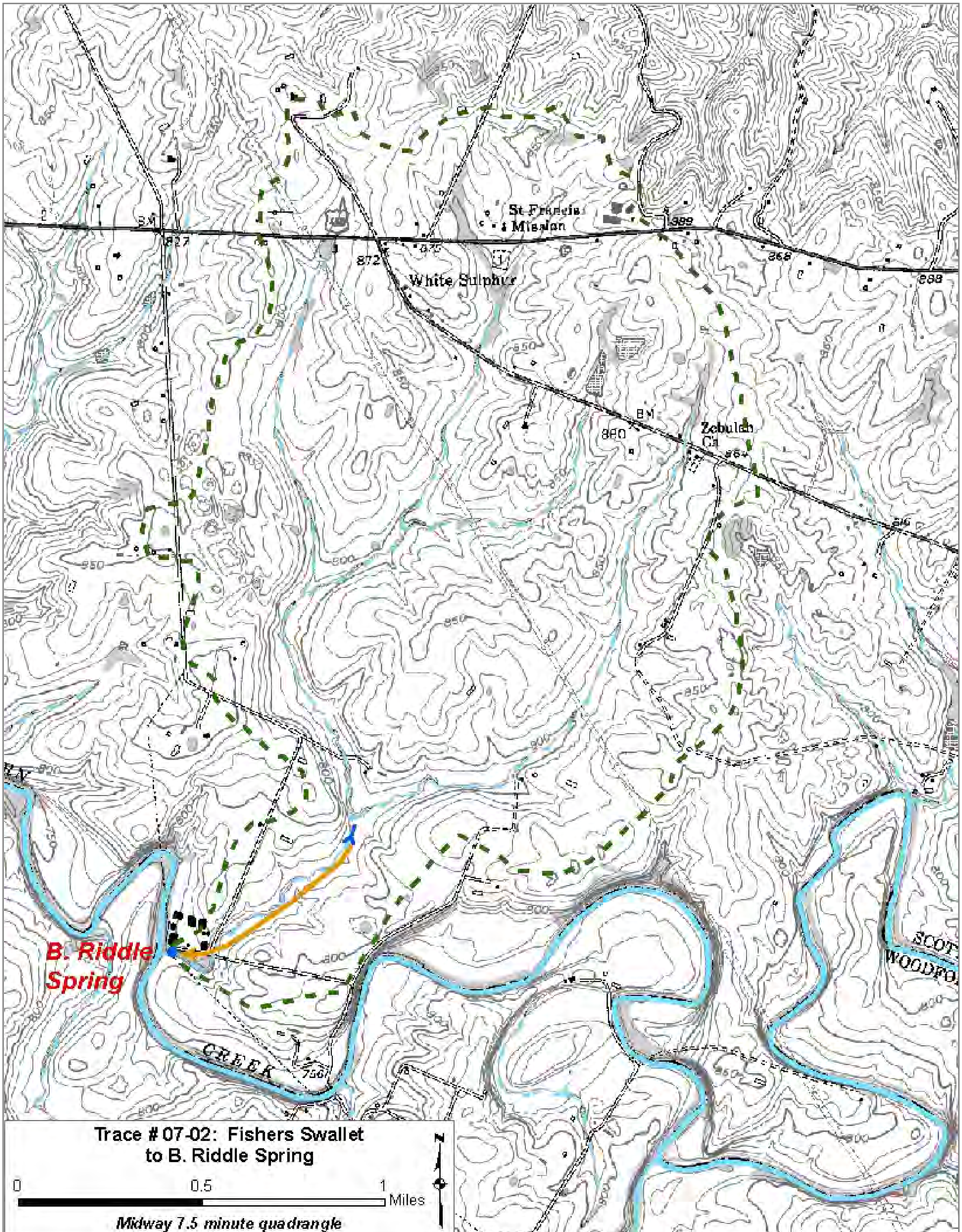
Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Slick Falls Swallet	Eosine 5/15/06 06-06	2 oz	0.1	No	Elkdale Sp (+++) 5/22/06	**5011**	**> 725**

Figure 30. Tracer Data for Elkdale Spring



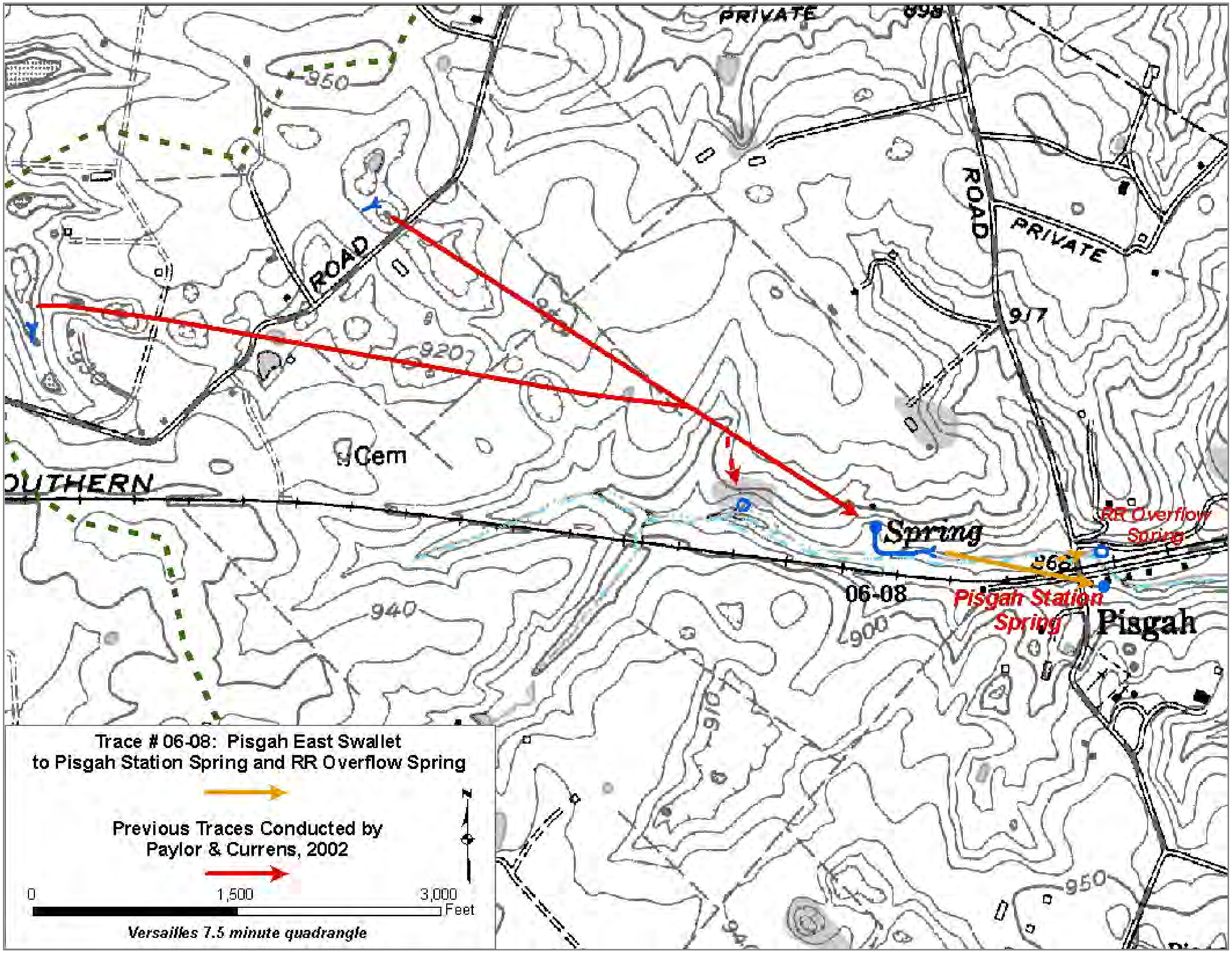
Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Nuckols Cave Swallet	Eosine 1/24/07 07-01	2 oz	0.15	No	Nuckols I-64 Sp (+) Box & House Sp (+) 1/26/07	**1463** **2741**	**> 747** **> 1400**
S. Nuckols Swallet	Fluor 3/16/07 07-03	1 oz	0.05	No	Fawn Leap Sp (++) Nuckols OF Sp (+++) Nuckols I-64 Sp (+++) Box & House Sp (+++) 3/21/07	**7714** **5134** **5688** **6952**	**> 1596** **> 1053** **> 1147** **> 1402**
S. Nuckols Swallet	Eosine 10/24/07 07-04	3 oz	0.15	No	Fawn Leap Sp (?) 10/29/07 ~ 2.5x background (overflow)	**7714**	**> 1596**
Hurstland Sinking Sp	Fluor 12/14/07 07-05	5 oz	0.02	No	Fawn Leap Sp (+++) 12/17/07	**6900**	**> 2379**

Figure 31. Tracer Data for Fawn Leap Spring and Nuckols Farm springs



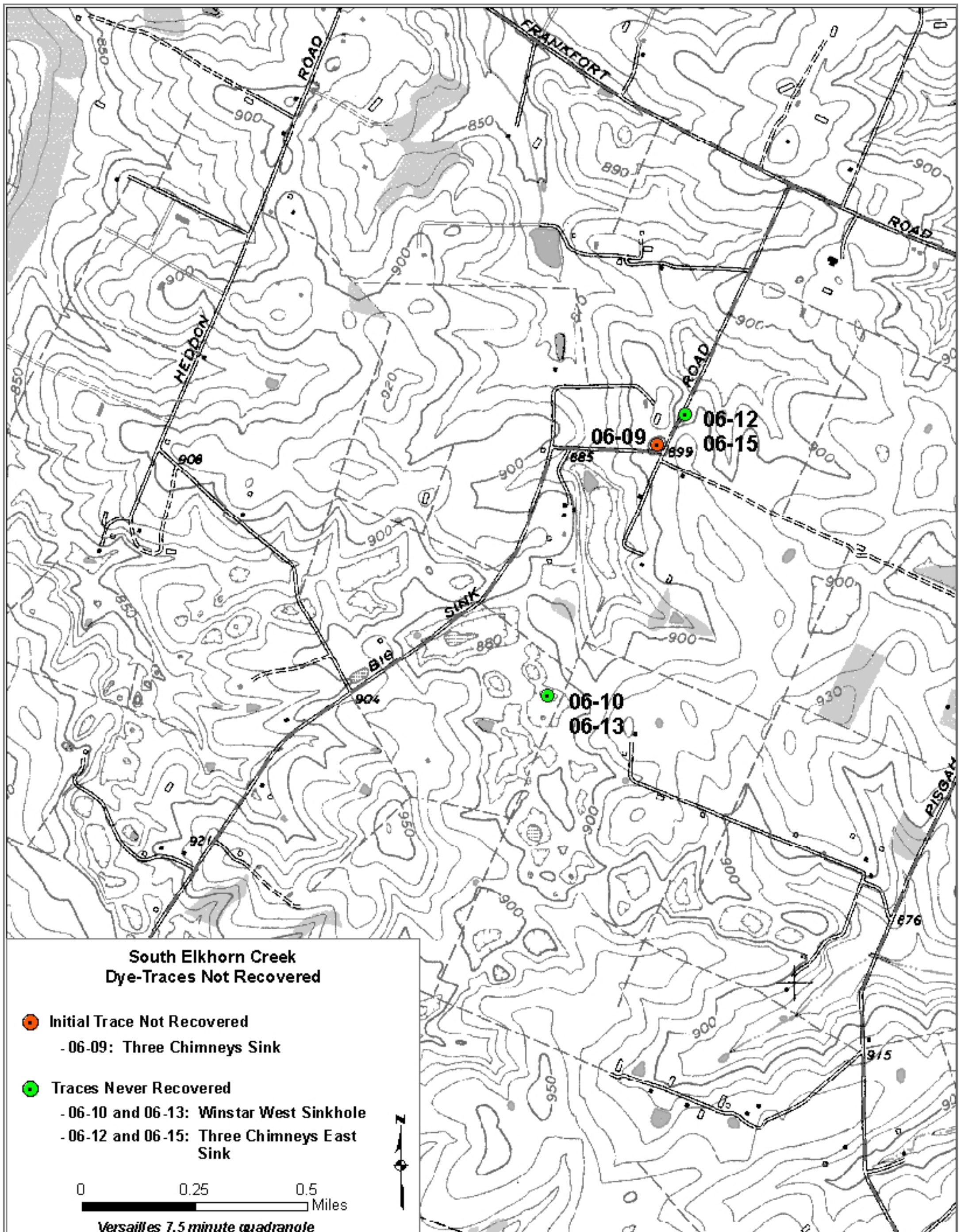
Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Fishers Swallet	Eosine 3/7/07 07-02	2 oz	0.05 *	No	Riddle Sp (+++) 3/14/07	**3262**	**> 466**

Figure 32. Tracer Data for B. Riddle Spring



Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Pisgah E Swallet	SRB 6/21/06 06-08	1 oz	0.05	No	RR/Pisgah Sta Sprs (+) 6/27/06	**1337**	**> 223**

Figure 33. Tracer Data for Pisgah Station Spring and RR Overflow Spring



Injection Site	Tracer and Injection Date	Amount	Recharge (ft^3/s)	Flow Induced	Detection Sites and First Recovery Dates	Inferred Distance (ft)	Inferred Velocity (ft/day)
Three Chimneys Sink	SRB 8/25/06 06-09	2 oz		Yes-200 gallons	Not Recovered on first attempt	N/A	N/A
Winstar W Sinkhole	Eosine 8/25/06 06-10	2.5 oz		Yes-200 gallons	Not Recovered	N/A	N/A
Three Chimneys E Sink	Fluor 9/26/06 06-12	5 oz		Yes-200 gallons	Not Recovered	N/A	N/A
Winstar W Sinkhole	Eosine 9/26/06 06-13	8 oz		Yes-400 gallons	Not Recovered Replication of 06-10	N/A	N/A
Three Chimneys E Sink	Fluor 11/3/06 06-15	16 oz		Yes-800 gallons	Not Recovered Replication of 06-12	N/A	N/A

Figure 34. Tracer Tests Not Recovered

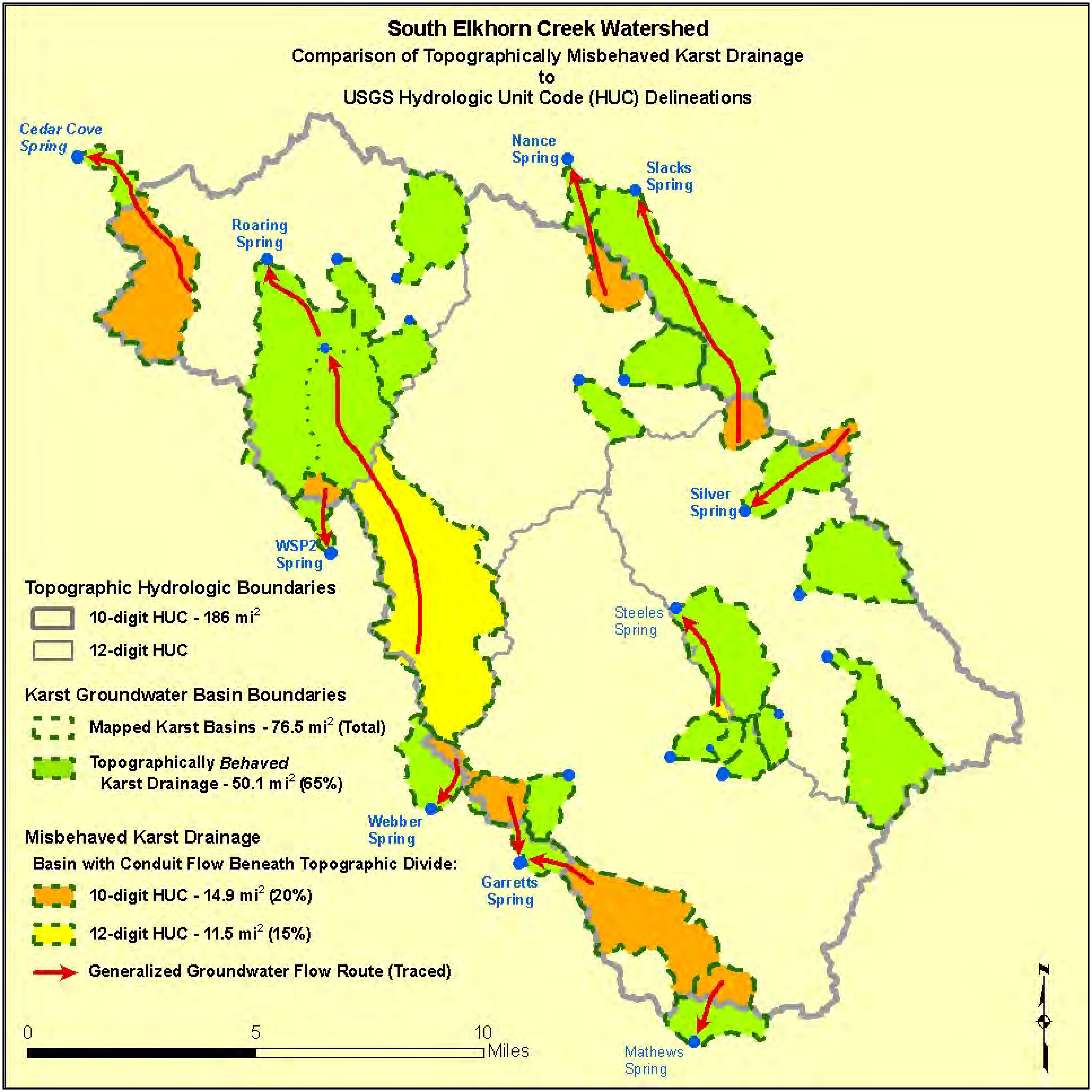


Figure 35. Comparison of Misbehaved Karst Drainage to USGS Hydrologic Unit Code (HUC) Delineations